MONTHLY WEATHER REVIEW

CLEVELAND ABBE, Editor.

VOL. 42, NO. 8
W. B. No. 536

AUGUST, 1914

CLOSED SEPT. 30, 1914
ISSUED NOV. 16, 1914

INTRODUCTION.

During the summer of 1913 the Secretary of Agriculture established a board to reorganize the system of publications of the Department of Agriculture. In accordance with the proceedings of the board and the suggestions from representatives of the Weather Bureau, the "Bulletin of the Mount Weather Observatory" ceased to be published with the completion of its volume 6. Any subsequent contributions from the members of the research staff that would have been proper for that Bulletin will be incorporated in the Monthly Weather Review. The climatological service of the Weather Bureau will be maintained in all its essential features, but its publications, so far as they relate to purely local conditions, will be incorporated in the monthly reports for the respective States, Territories, and colonies.

Beginning with January, 1914, the material for the Monthly Weather Review will be prepared and classified in accordance with the following sections:

SECTION 1.—*Aerology.*—Data and discussions relative to the free atmosphere.

SECTION 2.—*General meteorology.*—Special contributions by any competent student bearing on any branch of meteorology and climatology, theoretical or otherwise.

SECTION 3.—*Forecasts and general conditions of the atmosphere.*

SECTION 4.—*Rivers and floods.*

SECTION 5.—*Bibliography.*—Recent additions to the Weather Bureau library; recent papers bearing on meteorology.

SECTION 6.—*Weather of the month.*—Summary of local weather conditions; climatological data from regular Weather Bureau stations; tables of accumulated and excessive precipitation; data furnished by the Canadian Meteorological Service; monthly charts Nos. 1, 2, 3, 4, 5, 6, 7, 8, the same as hitherto.

In general, appropriate officials will prepare the six sections above enumerated; but all students of atmospherics are cordially invited to contribute such additional articles as seem to be of value.

The voluminous tables of data and text relative to local climatological conditions that, during recent years, have been prepared by the 12 respective "district editors" will be omitted from the Monthly Weather Review, but will in future be collected and published by States at selected section centers.

The data needed in Section 6 can only be collected and prepared several weeks after the close of the month whose name appears on the title page; hence the REVIEW as a whole can only issue from the press within about eight weeks from the end of that month.

It is hoped that the meteorological data hitherto contributed by numerous independent services will continue as in the past. Our thanks are especially due the directors and superintendents of the following:

The Meteorological Service of the Dominion of Canada.
The Central Meteorological and Magnetic Observatory of Mexico.
The Director General of Mexican Telegraphs.
The Meteorological Service of Cuba.
The Meteorological Observatory of Belen College, Habana.
The Government Meteorological Office of Jamaica.
The Meteorological Service of the Azores.
The Meteorological Office, London.
The Danish Meteorological Institute.
The Physical Central Observatory, St. Petersburg.
The Philippine Weather Bureau.
The General Superintendent United States Life-Saving Service.

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SECTION I.—AEROLOGY.

THE TOTAL RADIATION RECEIVED ON A HORIZONTAL SURFACE FROM THE SUN AND SKY AT MOUNT WEATHER, VA.

By HERBERT H. KIMBALL.

[Dated Mount Weather, Va., Aug. 13, 1914.][1]

I. STANDARDIZATION OF CALLENDAR RECORDING PYRHELIOMETERS. (1)

Description of pyrheliometer.—The receiving part of this pyrheliometer is made up of four platinum grids wound in series in two pairs, each pair constituting an electrical resistance thermometer. The grids are wound on a horizontal mica plate fixed in a sealed and exhausted glass bulb, the top of which is hemispherical. The pair of grids constituting one of the thermometers is coated with black enamel, and the relative positions of the four grids are shown in figure 1. When exposed to radiation the blackened thermometer is raised to a higher temperature than the other, the wires of which are naked. According to Callendar the difference in temperature of the two thermometers is very nearly proportional to the intensity of the radiation falling upon them. An automatic registration of this temperature difference is effected by placing the two thermometers in two arms of a self-adjusting Wheatstone bridge, which has a pen so arranged that it traces on a record sheet wound on a revolving drum the varying difference in resistance of the two thermometers due to their difference in temperature.

Comparison of Marvin and Callendar pyrheliometers, when exposed to solar radiation only, at normal incidence.—A certificate is furnished with each Callendar pyrheliometer, which gives a factor by means of which recorded differences in resistance of the two thermometers may be reduced to gram-calories of heat received by them each minute per square centimeter of area. This factor necessarily assumes that the recorded difference in resistance of the two thermometers is strictly proportional to the intensity of the radiation to which they are exposed, without regard to the magnitude of this intensity, the wave length of the radiant energy, or the temperature of the resistance grids.

Both direct solar radiation and diffuse sky radiation vary in intensity and in quality from day to day, and from hour to hour of the same day. They also differ from each other in both quality and intensity. It seemed desirable, therefore, to compare records obtained from a Callendar pyrheliometer with the readings of some other instrument before undertaking to express in absolute units records obtained from the Callendar instrument when exposed to both sun and sky radiation. For this purpose Callendar pyrheliometers No. 9860 and No. 9861 were fitted with tubes about 3¾ inches in diameter and 20 inches long, blackened inside, and containing two diaphragms, one just above the case containing the thermometers, the other at the outer end of the tube. The distance between these diaphragms was about 15 inches. The outer diaphragm contained an opening 2½ inches square, and the inner diaphragm an opening only slightly in excess of the area of the grids constituting the thermometers, or about 2¼ inches square. The angular opening between two parallel sides of the outer diaphragm as seen from the thermometers was therefore about 9°. This is slightly greater than the angle subtended by the circular opening in the outer diaphragm of the Marvin pyrheliometer as seen from the thermal element.

The glass cover of Callendar pyrheliometer No. 9860 has been accidently broken and removed. Previous to this, however, in February, 1911, both No. 9860 and No. 9861 were compared with Smithsonian silver disk pyrheliometer No. 1, and were found to read 10 per cent and 9 per cent low, respectively.

The two Callendar pyrheliometers thus shielded from sky radiation were equatorially mounted on a common support, and kept pointed to the sun by clockwork, with their receiving surfaces normal to the direction of the incident solar rays. They were exposed on a shelf in a third story window of the Physical Laboratory (see *A*, fig. 3), beside a Marvin pyrheliometer. This latter was standardized by comparison with Smithsonian silver disk pyrheliometer No. 1, and comparative readings between the two are frequently made. Smithsonian No. 1 has also been recompared from time to time with pyrheliometers in use at the Astrophysical Observatory of the Smithsonian Institution. By means of these precautions it is believed that we are able to express the readings of the Marvin pyrheliometer in heat units of the *Smithsonian revised scale of pyrheliometry* (2). Most of the comparisons of the Callendar pyrheliometers have been made with Marvin pyrheliometer No. 3, the comparisons of which with the Smithsonian instrument have given very constant ratios.

In obtaining comparisons between the Marvin and the Callendar pyrheliometers the latter have usually been allowed to make a continuous record for a half-day period, the record for the whole day being interrupted at noon in order to obtain the zero line on the record sheet. The Marvin pyrheliometer has been read at frequent intervals throughout the day, eight readings in eight consecutive minutes usually constituting a series, and these readings have been compared with the Callendar record made simultaneously.

Between August 15 and 30, 1912, 29 comparisons were obtained between a Marvin pyrheliometer and Callendar No. 9860. The results are summarized in Table 1. Between July 27, 1912, and March 19, 1913, about 130 comparisons were obtained between a Marvin pyrheliometer and Callendar No. 9861, and the results are summarized in Table 2.

The final results as tabulated were obtained by plotting the individual observations, with air masses (approximately the secant of the sun's zenith distance) as abscissas and the ratio $\frac{\text{Callendar}}{\text{Marvin}}$ as ordinates. In the case of No. 9860, without a glass cover, there is no apparent difference between the values of these ratios from morning and

[1] In Part II observational data have been included to Sept. 30, 1914, the date on which radiation measurements were discontinued at Mount Weather, Va.

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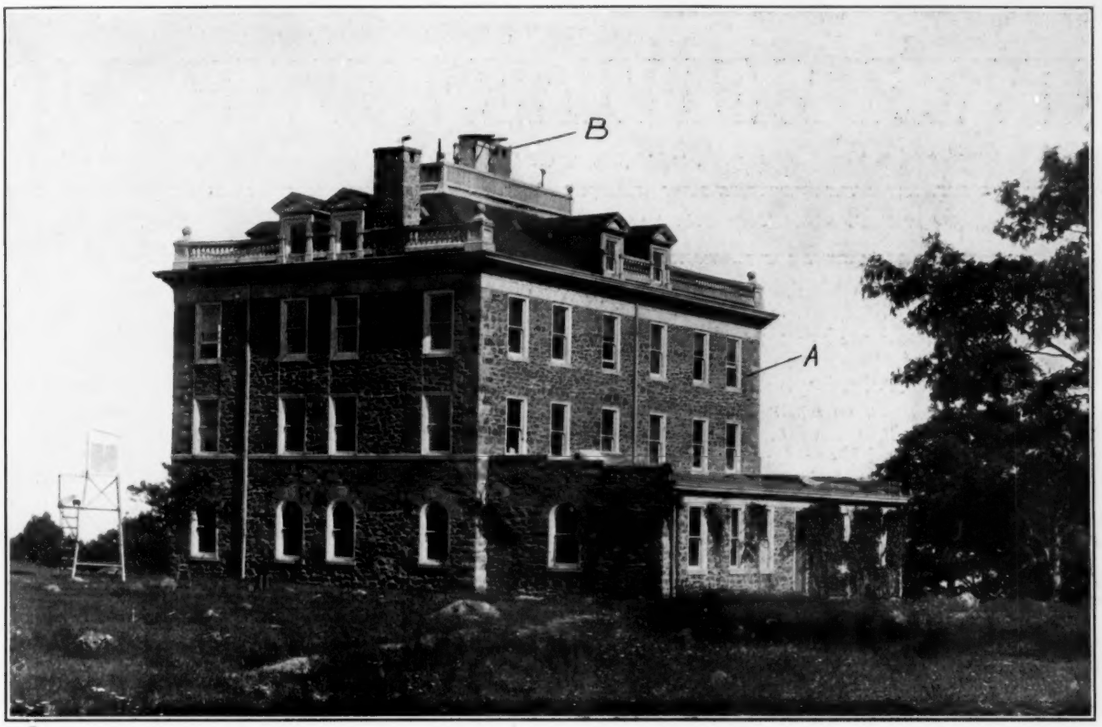

FIG. 3.—Physical laboratory, Mount Weather, Va. *A* indicates the afternoon window exposure for the Marvin pyrheliometer; *B*, the exposure for the Callendar pyrheliometer.

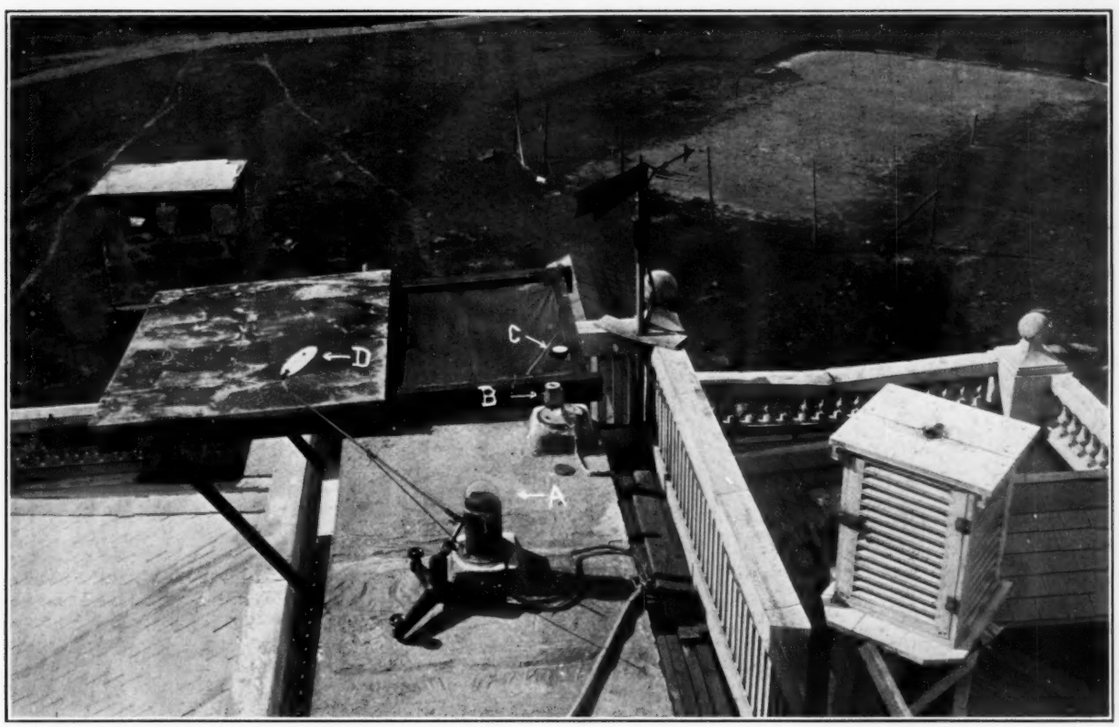

FIG. 4.—Exposure of radiation instruments on roof of the physical laboratory, Mount Weather, Va.

afternoon observations. In the case of No. 9861, with a glass cover, the ratios from morning observations are decidedly higher than the ratios from afternoon observations, for zenith distances of the sun less than 78.7°.

From Table 1 it is seen that Callendar No. 9860 reads slightly lower than the Marvin instrument with the sun less than 50° from the zenith, and higher than the Marvin instrument with the sun more than 60° from the zenith.

From Table 2 it is seen that Callendar No. 9861 reads higher than the Marvin instrument with the sun more than 79° from the zenith, and with a higher sun reads lower than the Marvin, especially in the afternoon.

Since No. 9860 and No. 9861 read practically alike in February, 1911, before the glass case was removed from No. 9860, the results in Tables 1 and 2 indicate that the removal of its case increased the readings of No. 9860 by at least 10 per cent.

Comparison of Marvin and Callendar pyrheliometers when exposed to radiation of varying intensity.—In order to determine the effect of radiation intensity upon the indications of Callendar pyrheliometers, Marvin No. 3 was mounted in the place of No. 9860, beside No. 9861, and on the same support. The diameter of the diaphragmed tube of No. 9861 was enlarged to 4½ inches so as to admit of ventilation at the bottom, and was shortened so that there was only about 12 inches between the two diaphragms, leaving the outer one only about 13 inches from the receiving surface of the thermometers. The opening in the outer diaphragm was made 2¾ inches square, which gave an angular opening of 12° between its parallel sides, and 17° between diagonally opposite corners, as seen from the surface of the receiving grids. A disk with segments that could be opened different amounts was mounted above the two pyrheliometers, with its driving shaft between them. By rotating this disk it was possible to shade both instruments the same amount and to any desired extent.

TABLE 1.—*Summary of comparisons of Callendar pyrheliometer No. 9860* (WITHOUT *glass envelope*) *inclosed in a diaphragmed tube, with Marvin pyrheliometer No. 6.*

Sun's zenith distance.....	25.0°	48.3°	60.0°	66.5°	70.7°	73.6°	75.7°
Ratio, $\frac{\text{Callendar}}{\text{Marvin}}$.....	0.97	0.99	1.01	1.03	1.05	1.08	1.10

TABLE 2.—*Summary of comparisons of Callendar pyrheliometer No. 9861* (WITH *glass envelope*) *inclosed in a diaphragmed tube, with Marvin pyrheliometers No. 3 and No. 6.*

Sun's zenith distance.	25.0°	48.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	79.8°	80.7°	81.5°
Ratio, $\frac{\text{Callendar}}{\text{Marvin}}$ a. m.	0.87	0.89	0.92	0.94	0.96	0.97	0.98	0.99	1.00	1.01	1.03	1.05
Ratio, $\frac{\text{Callendar}}{\text{Marvin}}$ p.m.	0.78	0.85	0.85	0.88	0.91	0.93	0.96	0.98	1.00	1.01	1.03	.....

TABLE 3.—*Summary of comparisons of Callendar pyrheliometer No. 9861 and Marvin pyrheliometer No. 3 when both are shaded different amounts.*

Percentage of shade.		0	50	70	80	90
Ratio, $\frac{\text{Callendar}}{\text{Marvin}}$	a. m.	1.00	1.04	1.09	1.12	1.19
	p.m.	1.00	1.06	1.11	1.15	1.17

Between June 18 and August 20, 1913, 45 comparisons were obtained between these two instruments when shaded from 50 to 90 per cent. The comparisons were made near midday and were generally both preceded and followed by unshaded comparisons of the instruments. The results, reduced to bring the two instruments into accord when unshaded, are summarized in Table 3.

With the sun at zenith distance 78.7° (air mass 5) its radiation intensity at normal incidence is reduced by atmospheric absorption from its zenithal intensity by approximately 50 per cent, the diminution being much greater for short waves than for long waves. Table 2 shows that this decreased intensity is accompanied by an increase in the ratio, $\frac{\text{Callendar}}{\text{Marvin}}$ of more than 20 per cent, while Table 3 shows an increase of only 5 or 6 per cent.

This greater increase in Table 2 as compared with that in Table 3 is probably due to the decrease in the proportion of short wave radiation in the solar spectrum with increase in the sun's zenith distance. Polished platinum has a much higher coefficient of absorption for radiation of short wave lengths than for radiation of long wave lengths (3). In consequence the bright grids of the Callendar pyrheliometer absorb relatively more of the solar radiation at noon than when the sun is at a greater zenith distance, thereby diminishing the value of the ratio, $\frac{\text{Callendar}}{\text{Marvin}}$, as shown. An even more marked decrease in this ratio is found in the second part of Table 4 as compared with the first part, the comparisons being between total solar radiation and the radiation transmitted by a ray filter, to be described later.

Difference in results of a. m. and p. m. comparisons.—An attempt has been made to ascertain the cause of the difference in the results of a. m. and p. m. comparisons between Callendar pyrheliometer No. 9861 and a Marvin pyrheliometer. These differences are not peculiar to No. 9861, as they were found when comparing the Callendar instrument in use at Washington, D. C., with Smithsonian No. 1, and also when comparing the Callendar in use at Madison, Wis., with the Marvin, except that in this latter case the Callendar read relatively too high in the afternoon. Patterson (4) also obtained higher values of the ratio $\frac{\text{Callendar}}{\text{Angström}}$ in the afternoon than in the morning.

In order to eliminate the effects of excessively heating the Callendar instrument, the fiber tube used previous to June, 1913, which fitted tightly upon the case of the pyrheliometer, was replaced by the larger aluminum tube, already referred to, leaving an annular space about ¾ inch wide between the tube and the case, for purposes of ventilation. This had no effect upon the results, however.

An awning was hung over the window in which the pyrheliometers were exposed, so as to cut off any possible reflection from the side of the building into the diaphragmed tube; and, finally, the Callendar pyrheliometer was exposed on a platform above the roof of the building; but there was no diminution in the difference between morning and afternoon ratios. However, in the course of these investigations the Callendar pyrheliometer with its diaphragmed tube was turned 90° about its vertical axis, and the higher values of these ratios were then obtained in the afternoon instead of in the morning, as heretofore.

Figure 1 shows the orientation of the black and bright grids of the pyrheliometer with reference to the meridian, N—S. The "First position" represents the orientation when the comparisons summarized in Table 2 were obtained, and the "Second position" represents the orientation after the instrument had been turned 90°

as described above. In the first part of Table 4 are summarized 29 sets of comparative readings between Callendar No. 9861 and Marvin No. 3, obtained between July 4 and July 8, 1913, with the Callendar oriented as shown in the "First position," figure 1, and 34 sets of comparative readings obtained between June 9 and July 16, 1913, with the Callendar oriented as shown in the "Second position," figure 1.

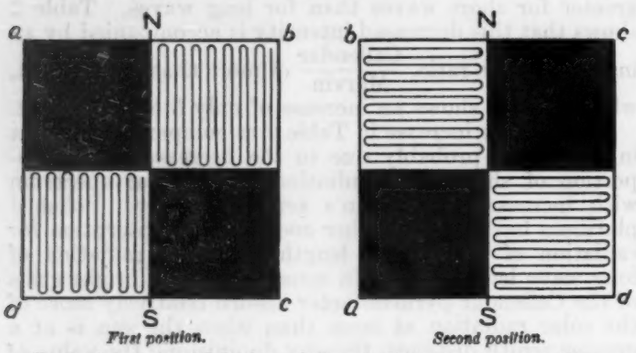

FIG. 1.—Orientation of Callendar pyrheliometer with reference to the meridian.

TABLE 4.—*Summary of comparisons of Marvin pyrheliometer No. 3 and Callendar pyrheliometer No. 9861 with the grids of the latter differently oriented.*

Callendar in "First position." (Fig. 1.)				Callendar in "Second position." (Fig. 1.)			
a. m.		p. m.		a. m.		p. m.	
Sun's zenith distance.	Ratio, Callendar / Marvin.	Sun's zenith distance.	Ratio, Callendar / Marvin.	Sun's zenith distance.	Ratio, Callendar / Marvin.	Sun's zenith distance.	Ratio, Callendar / Marvin.
1. TOTAL SOLAR RADIATION.							
°		°		°		°	
75.5	1.016			75.4	0.936		
				73.4	0.930	72.6	1.089
70.4	1.006	69.5	0.963	71.0	0.944	70.2	1.046
67.0	0.956	65.0	0.931	66.8	0.906	65.6	1.035
57.2	0.954	59.4	0.906	58.0	0.881	59.8	0.982
48.9	0.917	47.2	0.890	46.8	0.864	45.2	0.990
27.0	0.950	23.5	0.912	27.0	0.871	27.0	1.002
2. SOLAR RADIATION TRANSMITTED THROUGH RAY FILTER.							
60.0	0.852	60.0	0.679			60.0	0.852
48.7	0.846	48.7	0.748	48.7	0.765	48.7	0.858
40.0	0.843	40.0	0.782	40.0	0.742	40.0	0.861

In the second part of Table 4 are summarized 33 sets of comparisons with No. 9861 in the "First position" and 14 sets with it in the "Second position," obtained between February 26 and April 17, 1914, inclusive, with a ray filter placed alternately in front of first the Callendar and then the Marvin pyrheliometer. The readings of the Marvin pyrheliometer were plotted—air mass against logarithms of instrumental measurements—to facilitate the interpolation of measurements synchronous with the record by the Callendar pyrheliometer.

The ray filter was made by the United States Bureau of Standards, and consists of the following parts:

1. A glass cell 21 mm. deep containing a solution of $Cu(NO_3)_2$.
2. A gelatine film dyed by uranine.
3. A gelatine film dyed by alizarine red.
4. A gelatine film dyed by victoria blue.

The transmission coefficients of this filter were specified by the author, and are shown in figure 2. They represent approximately the relation between the ratio of blue to red radiation intensities in skylight and sunlight, respectively, as derived from the studies of Nichols (5), and Abbot and Fowle (6). The filter was designed to reduce sunlight to approximately the blueness of skylight, but its transmission coefficients for green and yellow light are probably too high. Its transmission coefficient for the total solar radiation is about 1/8, while for diffuse sky radiation it is about 1/3. The difference between a. m. and p. m. values of the ratio $\frac{\text{Callendar}}{\text{Marvin}}$ appears to be

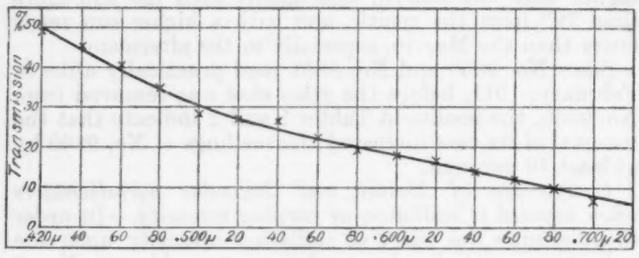

FIG. 2.—Transmission coefficients of ray filter.

slightly greater for solar radiation that has been depleted by passing through this ray filter than for total solar radiation.

Wiener (7), and Abbot and Fowle (8), have shown that the sky below the sun is warmer, and the sky above the sun is cooler, than the sky on either side the sun. The four grids of the Callendar pyrheliometer, when inclosed in a diaphragmed tube as already described, are exposed to different portions of the sky with reference to the sun as a center. Thus, referring to figure 1, and recalling that the angular opening between diagonally opposite corners of the outer diaphragm as viewed from the grids is 17°, it will be seen that with the pyrheliometer oriented as in the "First position" and the tube accurately pointed to the sun, in the morning the black grid *a* is above the axis of the tube, and must receive most of its sky radiation from points below the sun. The black grid *c*, on the other hand, is below the axis of the tube, and must receive most of its sky radiation from points above the sun, while the bright grids *b* and *d*, lying to the left and right of the axis of the tube, will receive most of their sky radiation from points to the right and left of the sun. In the afternoon these conditions are reversed, so that *b* and *d* receive most of their sky radiation from points below and above the sun, respectively, and *a* and *c* from points to the left and right of the sun. With the pyrheliometer oriented as shown in the "Second position," figure 1, the above a. m. and p. m. conditions relative to the exposure of the grids to the sky are reversed.

Since the value of the ratio $\frac{\text{Callendar}}{\text{Marvin}}$ depends upon the extent to which the pair of black grids is heated above the temperature of the bright grids, reference to Table 4 will show that the pair of grids that lies more nearly in the sun's vertical, and in consequence receives most of its sky radiation from points above and below the sun, is the more effectively heated. However, the data available do not indicate that we are justified in attributing this to the excess of sky radiation from these sections of the sky as compared with the radiation from sections to the right and left of the sun.

Comparison of measurements of the vertical component of solar radiation by Marvin and Callendar pyrheliometers.—The attempt to standardize Callendar pyrheliometers by mounting them in a diaphragmed tube proved unsatis-

factory. This method was therefore abandoned for one that is about to be described.

Callendar receivers No. 9861 and No. 13129 were exposed on the capstone of the central ventilating flue of the Physical Laboratory (see *B*, figure 3) with their thermometers horizontal. Their horizon was practically unobstructed in every direction. In figure 4, No. 13129, is seen in the central foreground at *A;* No. 9861 was exposed just beyond it at *B*. The instrument shown in figure 4 at *B* is a thermopile for measuring nocturnal radiation. Beyond this at *C*, projecting through a black cloth screen, is the receiving plate of a Sharpe-Millar photometer. The cloth screen covers the top of the photometer shelter when the roof is slid back as shown in the figure. The wind vane is pointing nearly due north.

Receiver No. 9861 recorded on a Callendar self-adjusting bridge, and No. 13,129 on a self-adjusting bridge constructed by Leeds and Northrup. The bridge wires of both these recorders have a resistance of 1 ohm for 200 mm. or 7.874 inches of length. Careful calibration with 0.1 ohm steps showed no variations in either wire greater than could be attributed to imperfect registration. The Leeds and Northrup register is shunted so that a difference of 0.1 ohm in the thermometers causes a movement of the pen of 1.016 inches on the record sheet. On the Callendar register a like difference in resistance causes a movement of 0.787 inch. The record sheets are ruled to tenths of inches. The time scale is 1 hour = 0.8 inch, and lines are ruled for 10 minute intervals.

Exposed as above described, the pyrheliometers give a continuous record of the difference in resistance of the black and bright grids due to the heating effect of the radiation received from the sun and sky. In order to compare this record with the readings of the Marvin pyrheliometer it is necessary to deduct from the total the effect due to sky radiation or, more strictly speaking, the effect of solar radiation reflected diffusely from the sky. This latter has been determined by producing an artificial eclipse of the sun for short periods, by interposing a movable circular screen 4 inches in diameter between the sun and the Callendar receiving grids, and about 22 inches from the latter, as shown at *D* in figure 4. At the receiving grids this screen subtends an angle of about 10°. The ¼-inch arm supporting the screen shades a strip of sky extending from the sun to the horizon and ½° to 2° wide, the width increasing with approach to the horizon. The screen has an equatorial mounting, but it is necessary to turn it by hand on its axis every two or three minutes in order to keep the pyrheliometer in the center of the shadow.

Figure 5 shows a record made with Callendar pyrheliometer No. 9861 on May 8, 1913. A cap was put over the receiver at 9:09 a. m., screening it from all radiation and fixing the zero line on the sheet, as shown. The other depressions in the record were caused by interposing the screen above described between the receiver of the pyrheliometer and the sun.

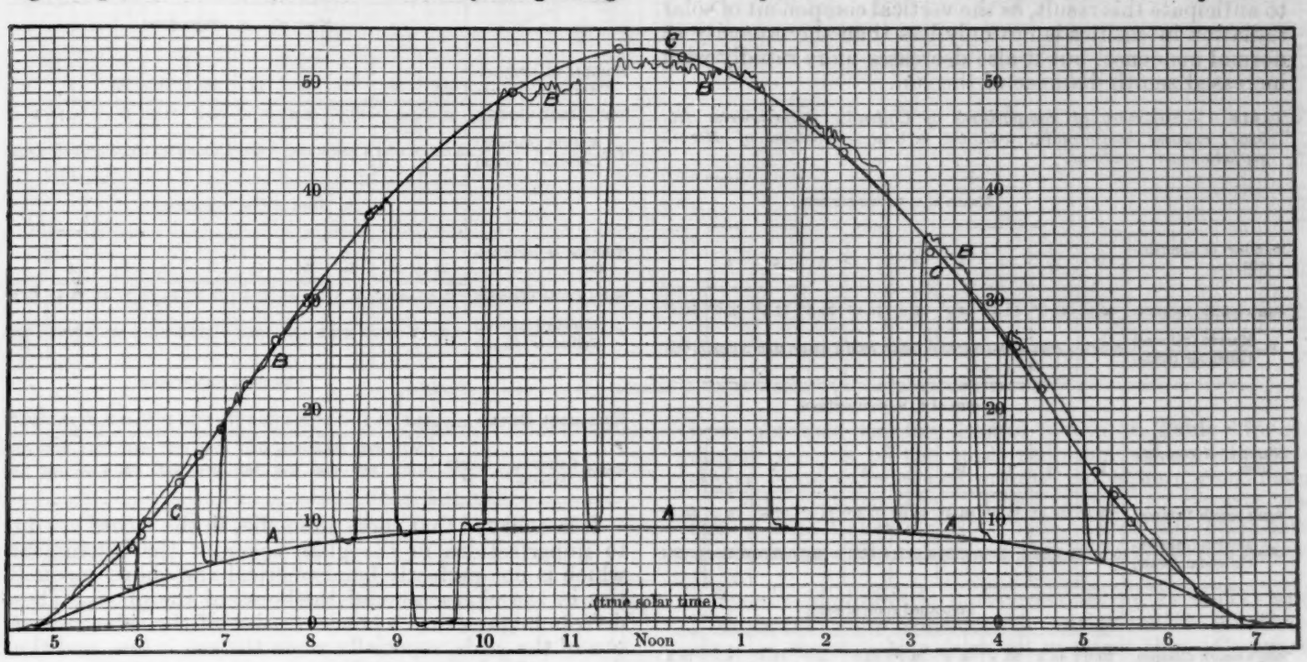

FIG. 5.—Records of solar and sky radiation at Mount Weather, Va., on May 8, 1913.

That part of the record (fig. 5) between the line *A A* and the zero or base line represents the heating effect of sky radiation upon the pyrheliometer. That part of the record between the line *A A* and the trace *B B*, made by the register pen, represents the heating effect upon the pyrheliometer of the vertical component of solar radiation. This latter may be compared with the vertical component of radiation intensities measured by the Marvin pyrheliometer, $H = Q \sin h.$, where h is the height of the sun above the horizon. The values of h have been computed for each observation from Ball's Altitude Tables (9). In figure 5 the values of H are plotted as circles in the curve *C C* from *A A* as a base line.

Table 5 summarizes comparisons between Marvin pyrheliometer No. 3 and Callendar pyrheliometer No. 9861, made as described above between March 28 and May 8, 1913. The vertical component of the radiation intensity measured by the Marvin instrument has been divided by the number of tenths of inches on the record sheet be-

tween a line similar to *A A*, figure 5, and the trace made by the register pen simultaneously with the readings of the Marvin pyrheliometer. The quotient, *F*, is the radiation equivalent of these tenths of inches, expressed in gram calories per minute per square centimeter of horizontal surface. The "smoothed comparisons" in Table 5 have been obtained by plotting the mean values of *F*, given in the first part of the table, against the air masses corresponding to the sun's zenith distance. The ratios, $\frac{\text{Callendar}}{\text{Marvin}}$, in the last part of the table, have been obtained by dividing the value of the reduction factor derived from the Callendar certificate (0.0251 for pyrheliometer No. 9861), by these smoothed values of *F*. It will be observed that these ratios have a higher value than the ratios in Table 2, and that the increase with increased zenith distance of the sun is also greater. Table 3 would lead us to anticipate this result, as the vertical component of solar radiation intensities is not only less than the intensity at normal incidence, but it also decreases more rapidly with increased zenith distance of the sun.

TABLE 5.—*Summary of comparisons of Callendar pyrheliometer No. 9861, exposed horizontally, with the vertical component of Marvin pyrheliometer readings.*

	Means of A. M. comparisons.									
Number of comparisons	17	12	14	9	8	7	6	8	4	7
Sun's zenith distance	30.0°	47.2°	58.6°	66.2°	71.2°	73.8°	75.8°	77.5°	78.6°	79.9°
$F = \frac{\text{Marvin (calories)}}{\text{Callendar (scale)}}$	0.0274	0.0264	0.0264	0.0263	0.0255	0.0256	0.0244	0.0223	0.0205	0.0187
	Means of P. M. comparisons.									
Number of comparisons	17	14	11	10	11	11	4	3	1	1
Sun's zenith distance	30.5°	45.6°	59.2°	66.5°	70.6°	73.6°	75.9°	77.6°	78.5°	80.0°
$F = \frac{\text{Marvin (calories)}}{\text{Callendar (scale)}}$	0.0272	0.0255	0.0244	0.0236	0.0229	0.0231	0.0221	0.0206	0.0190	0.0211
	Smoothed comparisons.									
Sun's zenith distance	30.0°	43.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	79.8°
F, a. m.	0.0274	0.0268	0.0264	0.0262	0.0259	0.0256	0.0244	0.0224	0.0203	0.0188
F, p. m.	0.0273	0.0255	0.0242	0.0236	0.0232	0.0230	0.0221	0.0208	0.0197	0.0188
Ratio, $\frac{\text{Callendar}}{\text{Marvin}} = \frac{0.0251}{F}$ a. m.	0.92	0.94	0.95	0.96	0.97	0.98	1.03	1.12	1.24	1.34
Ratio, $\frac{\text{Callendar}}{\text{Marvin}} = \frac{0.0251}{F}$ p. m.	0.92	0.99	1.04	1.07	1.08	1.09	1.14	1.21	1.28	1.34

In Table 6 are summarized similar comparisons between Callendar pyrheliometer No. 13129 and Marvin No. 3. There is so little difference between the a. m. and p. m. values of *F* that they have been combined to obtain the smoothed values and the ratio, $\frac{0.0247}{F}$, the numerator of which is derived from the Callendar certificate for this pyrheliometer.

These ratios are only slightly higher than the a. m. ratios for Callendar No. 9861, given in Table 2.

In the summary in Table 6 comparisons for zenith distances of the sun greater than 66.5° obtained between October 16, 1913, and February 2, 1914, have been omitted, as the Callendar instrument did not seem to be properly recording direct solar radiation. The record for November 6, 1913, reproduced in figure 6, shows the nature of the defect. After sunrise there was a considerable period during which no difference in resistance between the black and bright grids was recorded. In the evening, as the sun approached the horizon, too great a difference in resistance was recorded. This makes the record *B B* quite unsymmetrical about the noon line. The line *A A*, which represents the heating effect of sky radiation, does not show this lack of symmetry. The vertical components of Marvin pyrheliometer readings have been plotted as circles in the curve *C C* with *A A* as a base.

In searching for the cause of this anomaly in the Callendar record the pyrheliometer was turned on its support about its vertical axis approximately 120°. The record made in the early morning then showed too great a difference in resistance between the black and bright grids, while the record made a short time before sunset showed almost no difference.

TABLE 6.—*Summary of comparisons of Callendar pyrheliometer No. 13129, exposed horizontally, with the vertical component of Marvin pyrheliometer readings.*

	Mean of A. M. comparisons.									
Number of comparisons	14	28	38	16	16	16	11	13	6	6
Sun's zenith distance	28.0°	48.8°	59.7°	66.8°	71.0°	73.6°	75.6°	77.4°	78.7°	80.5°
$F = \frac{\text{Marvin (calories)}}{\text{Callendar (scale)}}$	0.0271	0.0.71	0.0265	0.0248	0.0256	0.0262	0.0255	0.0255	0.0240	0.0236
	Mean of P. M. comparisons.									
Number of comparisons	16	21	34	24	11	8	4	4	4	3
Sun's zenith distance	30.5°	48.3°	58.5°	66.8°	70.6°	73.4°	75.7°	77.4°	78.7°	80.0°
$F = \frac{\text{Marvin (calories)}}{\text{Callendar (scale)}}$	0.0268	0.0265	0.0253	0.0253	0.0256	0.0256	0.0247	0.0258	0.0240	0.0237
	Smoothed comparisons.									
Sun's zenith distance	25.0°	48.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	79.8°	80.7°
F	.0271	.0268	.0264	.0260	.0257	.0254	.0251	.0248	.0244	.0239	.0235
Ratio, $\frac{\text{Callendar}}{\text{Marvin}} = \frac{0.0247}{F}$	0.911	.925	.936	.950	.961	.972	.984	.996	1.01	1.03	1.05

It is believed that these anomalies in the record are due to imperfections in the glass cover of the instrument, which is not perfectly hemispherical and shows inequalities in the character and thickness of the glass. These defects might cause a concentration of the solar rays on one of the grids, especially when the sun is low, and thus destroy the symmetry of the record as noted above.

Comparison of measurements of short-wave radiation by Callendar and Marvin pyrheliometers.—As has already been shown, skylight is much richer in blue light than is solar radiation (**5**, **6**). Hence, it is not to be expected that the factors, *F*, of Tables 5 and 6, can be employed to reduce the Callendar record of sky radiation to heat units. We may, however, make use of the ratios in the second part of Table 4 to obtain such a factor, provided the ray filter has reduced sunlight to the blueness of skylight, as has been assumed. Unfortunately, the difference between the a. m. and the p. m. ratios, already discussed, introduces some uncertainty into the results, but the value of the factor appears to lie between 0.029 and 0.031, and 0.030 has been adopted.

Computation of the total radiation received on a horizontal surface.—In order to obtain factors for reducing records of the *total radiation* to heat units, measurements of sky radiation made by Callendar pyrheliometer No. 13129 on 40 different days, fairly well distributed throughout the period February 13, 1913–February 24, 1914, have been grouped according to the zenith distance of the sun at the time of the measurements. The results are summarized in Table 7. If the measurements are divided into two groups, the first covering the period February, 1913–August, 1913, and the second the period September, 1913–

February, 1914, the earlier period shows considerably more sky radiation than does the latter. This is in accord with other observations, which show that there was a gradual diminution in the haziness of the atmosphere throughout the year 1913 (**10**).

In the last part of Table 7 are given the proportions of average solar and sky radiation to the total, with the sun at different zenith distances. By means of these proportions, in connection with the factor 0.030 for sky radiation and the factors in Table 6 for solar radiation, have been obtained the first line of factors in Table 8 for reducing records of the total radiation with a cloudless sky to gram calories per minute per square centimeter of horizontal surface. These apply to records obtained with Callendar No. 13129, which has been used in obtaining daily records at Mount Weather since May, 1912.

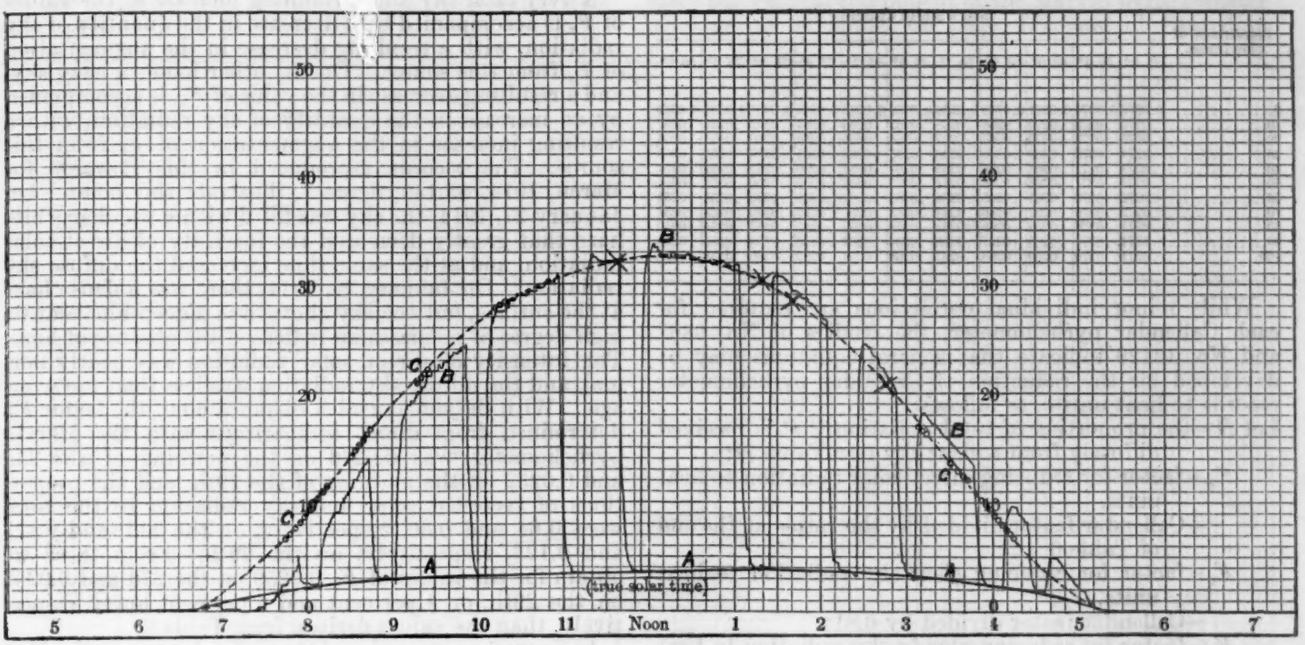

FIG. 6.—Records of solar and sky radiation at Mount Weather, Va., on November 6, 1913.

TABLE 7.—*Solar and sky radiation, as recorded by Callendar pyrheliometer No. 13129.*

	Mean of A. M. measurements.									
Number of measurements	14	28	38	25	22	20	14	16	8	7
Sun's zenith distance	28.0°	48.9°	59.7°	66.8°	71.1°	73.6°	75.7°	77.4°	78.7°	80.5°
Sky radiation	8.3	6.3	5.1	4.0	4.1	3.7	3.5	3.1	2.9	2.6
	Mean of P. M. measurements.									
Number of measurements	16	21	34	24	18	17	12	9	8	10
Sun's zenith distance	30.5°	48.7°	58.5°	66.8°	70.8°	73.4°	75.6°	77.5°	78.8°	80.1°
Sky radiation	8.5	6.2	5.2	4.6	4.2	3.6	3.2	3.1	2.8	2.6
	Smoothed means.									
Sun's zenith distance	25.0°	48.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	79.8°	80.7°
Sky radiation, Feb.–Aug., 1913	8.6	7.3	6.1	5.3	4.7	4.2	3.8	3.6	3.4	3.3	3.2
Sky radiation, Sept., 1913–Feb., 1914	.....	5.2	4.4	3.9	3.5	3.2	3.0	2.8	2.6	2.4	2.3
Sky radiation, Feb., 1913–Feb., 1914	8.7	6.3	5.0	4.3	4.0	3.7	3.4	3.1	2.9	2.7	2.6
Solar radiation	39.2	29.5	20.1	14.6	10.5	8.0	6.4	5.5	4.9	4.6	4.5
Total radiation	47.9	35.8	25.1	18.9	14.5	11.7	9.8	8.6	7.8	7.3	7.1
Ratio, $\frac{\text{Solar}}{\text{Total}}$	0.82	0.82	0.80	0.77	0.72	0.68	0.65	0.64	0.63	0.63	0.63
Ratio, $\frac{\text{Sky}}{\text{Total}}$	0.18	0.18	0.20	0.23	0.28	0.32	0.35	0.36	0.37	0.37	0.37

Spectro-photometric measurements by Ives (**11**) and Nichols (**12**) show considerable variations in the character of the radiation from an overcast sky. Comparisons between photometric and pyrheliometric measurements made at Mount Weather during the past year show a marked similarity between radiation from an overcast sky and direct solar radiation at midday, and marked differences between the radiation from a clear and an overcast sky, and between direct solar radiation with high and low sun. In obtaining factors for reducing the Callendar records of solar and sky radiation to heat units, when the sky is partly overcast, the factor 0.030 has been given a weight proportional to the amount of blue sky prevailing at the time. For reducing the radiation from an overcast sky to heat units the factors for reducing midday solar radiation have been employed, with a diminution of about 6 per cent as the sun approaches the horizon, corresponding to the variations in the ratios of Table 3 for a decrease in radiation intensities of 50 per cent. These factors are given in the last line of Table 8.

TABLE 8.—*Factors for reducing scale readings (tenths of inches) of records from Callendar pyrheliometer No. 13129 to gram-calories per minute per square centimeter of horizontal surface.*

$$F'_c = \frac{F'_0 SI + F_c (1.0-S) I_c}{SI + (1.0-S) I_c}$$

Percentage of cloudiness.	Sun's zenith distance.										
	25.0°	48.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	79.8°	80.7°
0	0.0276	0.0274	0.0271	0.0269	0.0269	0.0269	0.0268	0.0266	0.0264	0.0262	0.0259
10	.0276	.0273	.0270	.0268	.0268	.0267	.0266	.0264	.0262	.0259	.0257
20	.0275	.0273	.0270	.0267	.0267	.0266	.0265	.0263	.0260	.0257	.0254
30	.0274	.0272	.0269	.0266	.0266	.0265	.0263	.0261	.0258	.0256	.0253
40	.0273	.0271	.0268	.0266	.0265	.0264	.0262	.0260	.0257	.0254	.0251
50	.0273	.0271	.0268	.0266	.0264	.0263	.0262	.0259	.0256	.0253	.0251
60	.0272	.0270	.0268	.0266	.0264	.0263	.0261	.0259	.0256	.0253	.0251
70	.0272	.0270	.0267	.0266	.0264	.0263	.0261	.0259	.0256	.0253	.0251
80	.0271	.0270	.0268	.0266	.0264	.0263	.0262	.0259	.0257	.0254	.0252
90	.0271	.0270	.0268	.0267	.0265	.0264	.0262	.0260	.0258	.0256	.0253
100	.0271	.0270	.0269	.0268	.0267	.0266	.0264	.0262	.0260	.0258	.0256

While minor individual corrections are required for each Callendar pyrheliometer, the studies of No. 9861 and No. 13129 indicate that general equations may be developed for the reduction of Callendar pyrheliometer records to heat untits, as follows:

Let R = the proportion of total radiation that is received diffusely from a clear sky (see Table 7);

F_x = factor for reducing direct solar radiation to heat units,
= Callendar factor divided by the ratios at the end of Table 6;

F_1 = factor for reducing clear sky radiation to heat units,
= Callendar factor divided by 0.81;

F_c = factor for reducing cloudy sky radiation to heat units,
= F_x for solar zenith distance 25°, diminishing slightly with increased zenith distance of the sun;

S = the proportion of the sky that is unobscured by clouds.

With the sun shining in a cloudless sky the reduction factor for the total radiation becomes

$$F_0 \quad (1.0-R)F_x + RF_1. \qquad (1)$$

When clouds are present, the factor for reducing the total record obtained while the sun is shining becomes

$$F'_0 = (1.0-RS)F_x + RSF_1. \qquad (2)$$

If we wish to reduce the total record obtained during an hour with sunshine only a part of the time, we must weight F'_0 and F_c according to the proportional part of the total radiation to which each applies, as follows:

$$F'_c = \frac{F'_0 SI + F_c(1.0-S)I_c}{SI + (1.0-S)I_c}, \qquad (3)$$

where I and I_c are the relative intensities of the total radiation when the sun is shining and when it is obscured, respectively.

In Table 8 are given the values of F_0 (percentage of cloudiness = 0, and $S = 1.0$); F_c (percentage of cloudiness = 100, and $S = 0$); and F'_c (percentage of cloudiness from 10 to 90, and S from 0.9 to 0.1). The values adopted for I and I_c are 3 and 1, 2 and 1, 3 and 2, and 4 and 3, for solar zenith distances 25° to 63°, 64° to 74°, 75° to 79°, and 80° to 81°, respectively. For zenith distances of the sun greater than 81° the factors in the last column of Table 8 have been employed.

In the above equations, and also in Table 8, variations from day to day in the proportion of blue light in the solar spectrum, and also in the proportion of diffuse clear-sky radiation to solar radiation, have not been taken into account. It is believed, however, that these variations tend to compensate one another in their effects on the value of F_0.

A very clear sky and a resulting increase in the values of F_x is accompanied by a decrease in the quantity of sky radiation, with a resulting decrease in the augmentation of F_0 from this source. On the other hand, a hazy sky, and a resulting decrease in the value of F_x, is accompanied by an increase in the quantity of sky radiation, with a resulting increase in the augmentation of F_0 from this source. The records reproduced in this REVIEW for March, 1914, **42**:140, figure 1, illustrate this point. On January 23, 1914, the sky was filled with a peculiar white haze that greatly decreased the intensity of direct solar radiation, and at the same time increased the diffuse sky radiation. On January 29, 1914, there was a dense haze at the surface, but the sky above was a deep blue and its high degree of polarization indicated the absence of haze. The intensity of direct solar radiation was nearly normal, and the diffuse sky radiation was less than the average. With the sun at zenith distance 60.0° the factor F_x, determined from direct comparisons with the Marvin pyrheliometer, was 0.0236 on the morning of the 23d and 0.0252 on the morning of the 29th, and the proportions of recorded solar and sky radiation to the total were 0.64 and 0.36, respectively, on the 23d, and 0.875 and 0.125, respectively, on the 29th. From these we obtain for the values of F_0, 0.0259 on the 23d and 0.0257 on the 29th, or 4 per cent and 5 per cent lower, respectively, than the values derived from Table 8.

In figure 7 are reproduced the Callendar records for May 20, 1914, a very hazy or smoky day, and June 30, 1914, a very clear day except that the sky was from 0.1 to 0.2 covered with cumulus clouds during the afternoon. Just before noon on May 20, with the sun at zenith distance 21.2° and its hour angle from the meridian 42 minutes, the factor F_x, determined from direct comparisons with the Marvin pyrheliometer was 0.0253. The proportions of solar and sky radiation to the total were 0.76 and 0.24, respectively, and the resulting value of F_0 is 0.0264, which is 4 per cent lower than the value given in Table 8. Just before noon on June 30, with the sun at zenith distance 18.9°, and its hour angle from the meridian 48 minutes, the factor F_x, determined from direct comparisons with the Marvin pyrheliometer, was 0.0274. The proportions of solar and sky radiation to the total were 0.90 and 0.10, respectively, and the resulting value of F_0 is 0.0277, which is in accord with the value given in Table 8. With the sun at zenith distance 60°, the values of F_0, computed as above, are 0.0273 and 0.0271 for the forenoon and afternoon of May 20, and 0.0270 and 0.279 for the forenoon and afternoon of June 30, respectively. These are all closely in accord with the value 0.0271, derived from Table 8, with the exception of the one for the afternoon of June 30, when the presence of clouds is shown by the Callendar record to have been a disturbing factor.

On May 8, 1913 (see record, fig. 5), the values of F_0, computed as above for Callendar No. 9861, ranged between 0.0270 and 0.0281, for solar zenith distances less than 60.0°.

The probable error of F_x for a single observation averages ±0.0008, or ± 3 per cent, for zenith distances of the sun not greater than 75.7°. With lower sun the probable error increases rapidly, amounting to about ± 6 per cent for solar zenith distance 78.7°. With the sun so low, how-

ever, the radiation measured is but a small part of the total for the day.

The probable errors of F_o, F'_o, and F''_c may exceed slightly that for F_z. Also, the values of F_o and F''_c given in Table 8 appear to be somewhat too high in hazy weather and somewhat too low when the sky is free from haze.

hour lines, have been integrated by counting in each of these areas the number of squares bounded by the tenth-inch lines and the 10-minute time lines. In clear weather during the months October to February, inclusive, the records have been corrected by plotting on the record sheet the vertical component of the Marvin pyrheliometer readings, as explained on page 477, and illustrated in

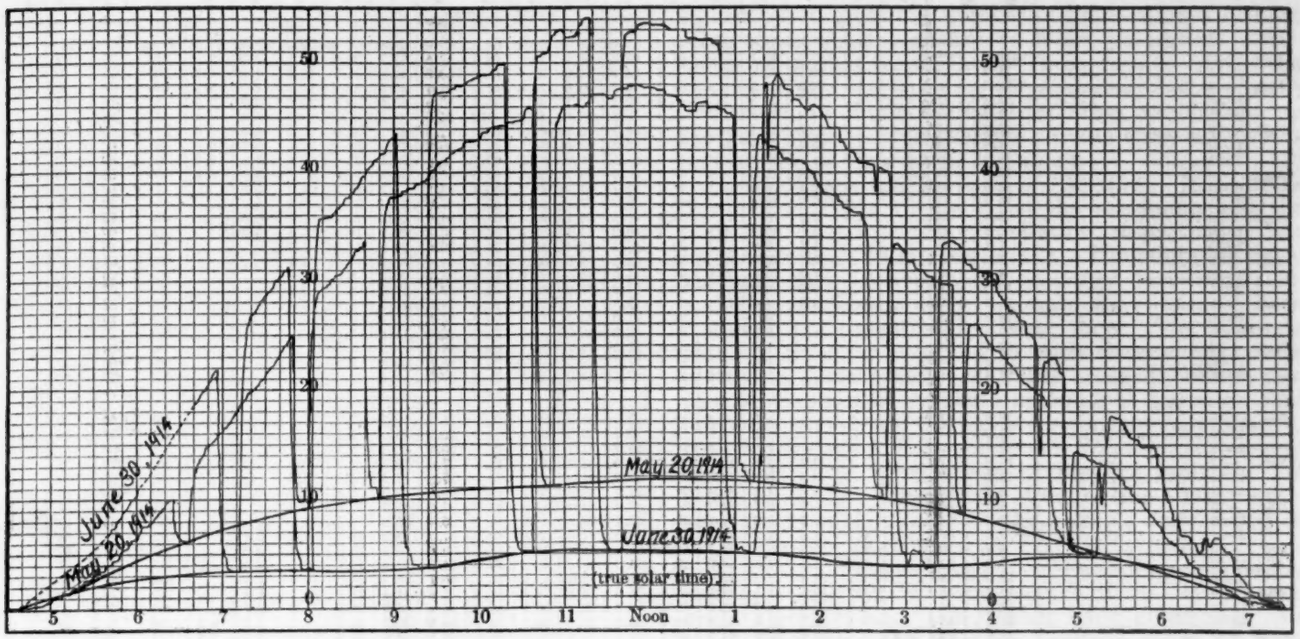

FIG. 7.—Records of solar and sky radiation at Mount Weather, Va., on May 20 and June 30, 1914.

II. MEASUREMENTS OF THE TOTAL RADIATION RECEIVED ON A HORIZONTAL SURFACE.

Callendar records reduced to heat units.—In Table 9 are summarized the decade averages of the total radiation recorded at Mount Weather, Va., since May 17, 1912, by Callendar pyrheliometer No. 13129. The records have been reduced to heat units by the following method:

1. The areas on the record sheet between the base line, the trace made by the register pen, and the successive figure 6. No corrections have been made during these months when the sky was overcast with clouds.

2. The proportion of the sky covered with clouds during each hour has been determined partly from an inspection of the Callendar records, and partly from the eye estimate of cloudiness recorded for each odd hour throughout the day in the "Daily Meteorological Record" for the station. The latter has been closely followed except when the clouds were some form of cirrus, in which case the proportion of the sky actually obscured by clouds may be materially less than the proportion occupied by the cloud sheet.

TABLE 9.—*Solar and sky radiation, expressed in gram-calories per square centimeter of horizontal surface, at Mount Weather, Va.*

[Lat. 39° 4′ N.; long. 77° 53′ W.; altitude, 540 meters.]

Decade.	Mean solar declination.	Mean solar h. a. at sunrise and sunset.	Decade average during hours ending (apparent time)— A. M. 5	6	7	8	9	10	11	Noon.	P. M. 1	2	3	4	5	6	7	8	Daily average.	Percentage of possible radiation.	Percentage of possible sunshine.	Mean daily cloudiness.
1912.	°	h. m.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	Gr.-c.	%	%	
May 17-20	+19.7	7 08	.....	0.2	4.0	17.5	36.7	54.8	61.0	62.6	68.0	73.1	68.1	47.6	37.2	29.9	13.1	2.7	0.2	576	77	77	3
21-31	21.2	7 13	0.2	4.2	16.7	31.6	43.8	52.8	64.2	74.0	72.4	68.0	53.3	42.9	28.9	16.6	4.5	0.4	569	75	68	5
June 1-10	22.6	7 19	0.2	4.9	16.3	32.0	49.6	61.9	70.3	69.0	76.6	67.7	61.4	46.5	31.6	17.3	4.0	0.4	606	79	62	5
11-20	23.3	7 22	0.2	3.9	11.7	24.5	29.4	40.9	49.1	47.1	47.7	45.7	40.5	36.6	23.8	10.3	2.9	0.3	415	54	34	8
21-30	23.3	7 22	0.3	5.1	14.4	28.7	39.7	45.9	52.1	56.5	49.4	45.6	35.2	28.3	20.7	10.7	3.4	0.3	436	58	35	8
July 1-10	22.7	7 19	0.5	8.2	20.6	33.3	44.8	60.4	66.1	70.7	69.4	63.0	51.5	44.1	32.0	19.2	4.9	0.5	587	79	69	4
11-20	21.4	7 14	0.2	5.3	16.1	31.9	45.9	54.0	60.5	62.6	58.7	47.3	40.2	28.7	18.7	11.3	4.7	0.5	487	67	52	7
21-31	19.4	7 06	0.1	2.6	11.4	19.3	32.9	48.0	53.1	59.9	67.6	60.6	48.0	38.1	27.4	12.4	3.8	0.2	485	69	47	5
Aug. 1-10	16.8	6 56	.....	2.1	9.4	22.6	33.2	46.3	55.9	59.7	55.6	47.6	45.3	36.9	24.6	12.7	3.0	0.1	455	68	39	6
11-20	13.9	6 46	.....	1.9	9.1	19.0	34.0	48.0	51.4	51.2	48.3	45.4	43.2	31.2	23.5	9.0	1.6	.....	417	65	33	7
21-31	10.4	6 34	.....	0.1	7.7	18.6	28.9	44.1	49.2	57.8	65.8	57.1	47.0	34.4	20.6	9.6	1.3	.....	444	73	39	4
Sept. 1-10	6.6	6 22	.....	0.4	6.0	16.7	27.6	36.3	46.2	56.1	60.4	58.1	44.7	34.3	20.4	7.5	0.6	.....	415	73	56	4
11-20	+ 2.8	6 09	.....	0.1	3.9	15.7	21.8	31.8	46.2	54.1	53.8	52.0	40.3	28.9	16.0	5.4	0.2	.....	368	69	42	5
21-30	− 1.1	5 56	.....	.....	1.1	6.0	12.9	20.1	26.2	32.4	35.3	34.8	29.0	21.5	11.4	3.0	.....	.....	234	48	34	7
Oct. 1-10	5.0	5 44	.....	.....	2.7	13.9	29.2	42.8	52.3	58.9	60.4	53.6	44.4	30.9	14.8	3.9	.....	.....	408	91	81	2
11-20	8.7	5 32	.....	.....	1.3	10.1	22.0	33.0	44.0	45.0	44.0	42.1	33.7	20.2	8.9	1.3	.....	.....	306	75	50	5
21-31	12.5	5 19	.....	.....	0.5	6.0	18.3	30.4	37.9	37.9	35.5	33.1	27.5	17.3	5.7	0.5	.....	.....	251	67	66	5
Nov. 1-10	15.9	5 07	.....	.....	0.1	4.5	14.2	22.6	29.8	31.4	31.1	29.6	24.6	14.7	5.6	0.4	.....	.....	209	62	55	6
11-20	18.6	4 55	.....	.....	.....	2.7	10.1	22.5	31.9	36.3	33.8	29.9	25.5	15.7	4.8	0.1	.....	.....	213	70	62	6
21-30	20.8	4 48	.....	.....	.....	2.1	10.4	21.8	32.0	39.0	36.0	30.7	22.9	13.1	3.0	.....	.....	.....	211	75	67	4
Dec. 1-10	22.4	4 42	.....	.....	.....	1.4	7.7	14.5	21.5	24.7	24.1	21.2	14.7	8.5	1.6	.....	.....	.....	140	53	36	6
11-20	23.3	4 38	.....	.....	.....	1.4	8.6	17.5	27.7	29.2	27.6	25.6	18.8	9.3	2.2	.....	.....	.....	168	66	57	5
21-31	23.4	4 38	.....	.....	.....	1.1	8.3	17.2	27.5	32.0	32.5	27.4	19.3	9.4	1.6	.....	.....	.....	176	70	60	5
1913.																						
Jan. 1-10	22.6	4 41	.....	.....	.....	1.5	7.8	16.3	22.0	25.7	27.3	25.6	18.7	10.3	2.5	.....	.....	.....	158	60	40	6
11-20	21.0	4 47	.....	.....	.....	1.2	8.0	16.0	22.5	29.2	30.4	25.2	20.2	11.0	2.7	.....	.....	.....	166	57	33	7
21-31	18.7	4 56	.....	.....	.....	1.9	9.2	17.3	25.3	31.7	31.5	27.1	20.0	12.3	3.1	.....	.....	.....	179	53	47	6
Feb. 1-10	15.8	5 07	.....	.....	0.3	5.3	16.3	28.7	38.6	42.3	45.4	42.4	33.4	19.5	7.1	0.4	.....	.....	280	73	75	4
11-20	12.5	5 18	.....	.....	0.4	6.7	18.0	29.3	38.9	43.4	43.3	39.9	27.9	17.6	6.5	0.6	.....	.....	272	63	61	5
21-28	9.3	5 30	.....	.....	0.5	4.4	14.4	26.5	31.7	39.3	36.2	28.6	30.8	20.8	6.8	1.0	.....	.....	241	50	32	7
Mar. 1-10	5.9	5 41	.....	.....	1.3	9.7	21.1	35.5	43.6	43.4	47.8	44.0	32.9	25.8	12.6	2.0	.....	.....	320	60	51	6
11-20	− 2.0	5 54	.....	.....	1.7	9.5	19.7	29.7	35.1	39.2	48.0	44.4	36.7	25.8	13.5	4.1	.....	.....	308	53	48	6
21-31	+ 2.2	6 07	0.1	3.4	12.5	23.0	33.2	40.5	44.9	53.0	44.9	37.2	28.3	16.4	4.6	0.1	.....	.....	342	55	44	6
Apr. 1-10	6.2	6 20	0.4	6.8	22.3	37.1	52.8	61.9	61.4	55.6	48.7	39.6	33.8	22.6	7.8	0.6	.....	.....	451	68	62	5
11-20	9.9	6 33	0.7	5.5	14.3	24.0	28.6	33.3	39.2	40.2	38.6	34.2	27.6	17.9	7.2	0.8	.....	.....	312	45	38	6
21-30	13.3	6 44	2.9	12.4	27.3	42.7	54.4	55.8	58.0	57.9	57.4	50.1	38.1	25.8	10.5	1.3	.....	.....	495	69	60	4
May 1-10	16.4	6 55	3.7	15.5	31.5	44.2	60.7	68.6	72.8	73.3	64.2	57.4	44.4	27.2	10.1	1.9	.....	.....	575	78	66	4
11-20	18.9	7 04	3.3	12.0	22.3	30.9	39.6	52.6	56.9	56.9	53.1	49.2	35.6	24.9	11.0	2.7	.....	.....	451	60	40	6
21-31	21.2	7 13	3.8	11.3	23.5	31.5	40.4	45.3	48.2	50.5	45.3	34.8	30.3	19.7	9.3	2.2	0.1	.....	396	52	34	7
June 1-10	22.6	7 19	0.4	7.2	18.6	31.3	44.2	59.4	70.2	75.8	73.6	69.6	58.8	48.0	31.0	17.3	4.8	0.5	611	80	70	3
11-20	23.3	7 22	0.5	7.7	19.2	38.6	51.6	65.2	72.5	80.1	74.7	68.6	60.7	48.1	30.5	16.5	4.0	0.3	639	84	69	3
21-30	23.4	7 22	0.3	4.5	11.9	19.2	25.4	34.0	38.7	45.1	51.8	44.4	37.2	31.4	24.4	11.3	3.3	0.3	383	51	37	7
July 1-10	22.7	7 20	0.4	6.2	18.7	33.4	45.1	59.8	65.8	65.6	61.0	58.5	58.8	44.3	28.4	13.0	3.2	0.4	563	76	64	4
11-20	21.4	7 15	0.3	4.4	13.1	26.5	38.3	46.2	58.8	60.4	58.4	53.9	48.6	35.2	23.4	12.6	4.8	0.5	484	67	50	6
21-31	19.4	7 07	0.1	5.2	16.6	31.2	45.8	58.8	64.6	65.0	60.5	53.9	40.8	26.5	22.9	11.2	3.1	0.2	506	72	54	6
Aug. 1-10	16.9	6 57	.....	3.4	10.3	23.5	31.4	44.2	53.0	59.2	54.1	47.7	43.2	30.3	21.8	9.7	1.7	.....	434	64	48	5
11-20	13.9	6 46	1.2	6.6	15.3	25.1	33.4	40.5	45.7	49.4	45.6	36.4	29.3	18.5	7.4	1.1	.....	.....	356	56	40	7
21-31	10.4	6 34	1.5	10.8	23.8	39.6	54.2	58.1	65.0	69.3	57.1	45.3	38.0	23.6	8.2	0.9	.....	.....	450	74	67	5
Sept. 1-10	6.7	6 22	0.4	5.8	17.5	31.4	44.8	51.0	55.6	60.1	53.6	45.2	34.0	20.4	7.2	0.7	.....	.....	427	75	68	4
11-20	+ 2.9	6 09	0.2	4.1	14.0	26.6	35.5	40.6	42.7	42.6	38.8	31.5	22.4	11.4	3.3	0.2	.....	.....	314	59	34	8
21-30	− 1.0	5 56	.....	2.3	12.4	26.2	41.0	51.3	52.8	50.8	45.9	36.8	25.6	13.5	3.3	0.1	.....	.....	362	74	58	5
Oct. 1-10	4.9	5 44	.....	1.2	7.5	17.1	24.6	29.5	34.4	37.0	29.9	27.5	20.9	9.2	1.8	.....	.....	.....	241	54	36	7
11-20	8.6	5 32	.....	0.8	7.3	17.8	26.5	31.8	34.9	38.2	36.4	26.0	16.5	7.3	1.1	.....	.....	.....	245	60	40	6
21-31	12.4	5 19	.....	0.4	6.5	15.2	27.3	35.1	37.1	36.0	30.4	26.1	18.2	7.6	0.7	.....	.....	.....	241	65	46	6
Nov. 1-10	15.8	5 07	.....	0.2	4.7	15.9	27.1	35.1	39.0	38.6	34.7	27.5	17.8	5.8	0.3	.....	.....	.....	247	73	69	5
11-20	18.6	4 55	.....	.....	2.6	8.8	16.0	26.2	32.8	32.5	28.7	22.4	12.6	3.9	.....	.....	.....	.....	186	61	44	8
21-30	20.8	4 48	.....	.....	2.8	9.9	18.2	22.9	23.7	22.9	20.5	14.9	8.6	2.3	.....	.....	.....	.....	147	52	42	7
Dec. 1-10	22.4	4 42	.....	.....	2.3	10.2	19.6	24.0	25.4	24.8	21.1	17.2	9.6	1.9	.....	.....	.....	.....	156	59	28	8
11-20	23.3	4 38	.....	.....	2.5	11.8	23.6	34.8	33.9	38.3	31.5	21.8	11.0	3.0	.....	.....	.....	.....	218	85	88	3
21-31	23.4	4 38	.....	.....	1.8	9.6	18.5	24.0	26.7	24.9	21.6	13.5	7.0	1.5	.....	.....	.....	.....	149	59	53	7
1914.																						
Jan. 1-10	−22.6	4 41	.....	.....	.....	1.0	8.4	15.0	20.6	24.6	22.1	17.1	11.1	6.1	1.5	.....	.....	.....	128	48	33	8
11-20	21.1	4 47	.....	.....	.....	2.3	11.0	19.1	29.8	31.4	32.0	30.6	18.9	10.9	2.8	.....	.....	.....	189	65	50	6
21-31	18.8	4 56	.....	0.1	3.3	11.6	21.8	29.0	34.4	33.3	32.2	24.3	12.2	3.6	0.2	.....	.....	.....	206	61	55	7
Feb. 1-10	15.8	5 07	.....	0.4	6.4	16.3	27.8	36.5	41.2	40.9	35.8	27.6	16.0	5.5	0.4	.....	.....	.....	255	66	61	5
11-20	12.6	5 18	.....	0.7	7.6	16.9	24.6	35.4	39.3	36.8	37.2	26.0	17.3	6.1	0.6	.....	.....	.....	248	57	50	7
21-28	9.4	5 29	.....	2.0	12.8	24.7	40.3	52.2	56.6	57.6	45 0	36.2	20.2	10.0	1.5	.....	.....	.....	359	74	63	5
Mar. 1-10	6.0	5 40	.....	1.8	11.7	22.4	33.4	42.8	51.7	47.6	44.2	30.6	19.3	10.0	2.3	.....	.....	.....	318	60	62	6
11-20	− 2.1	5 53	.....	2.5	12.7	26.9	43.6	60.0	56.3	56.6	47.5	37.8	25.4	12.9	3.4	.....	.....	.....	376	65	60	7
21-31	+ 2.1	6 07	0.2	6.2	17.6	27.3	38.3	46.0	53.3	49.1	43.7	33.0	24.6	13.8	4.9	0.3	.....	.....	358	57	56	7
Apr. 1-10	6.1	6 20	0.7	7.8	14.6	28.7	35.9	39.0	43.2	44.7	46.6	39.2	28.8	16.8	7.5	1.0	.....	.....	354	53	38	7
11-20	9.8	6 32	1.0	10.2	20.2	32.4	41.9	48.0	52.0	53.0	45.7	39.3	29.4	17.8	8.9	1.4	.....	.....	401	58	51	6
21-30	13.2	6 44	2.2	13.0	26.7	38.9	54.5	58.2	59.9	57.4	52.2	43.0	31.3	21.3	11.2	3.0	.....	.....	473	66	61	8
May 1-10	16.3	6 55	2.6	13.4	25.7	37.1	44.0	55.6	53.7	60.6	56.6	50.7	35.2	25.0	14.6	4.9	.....	.....	480	65	53	7
11-20	18.9	7 04	5.1	18.3	34.3	50.3	60.5	70.4	73.8	72.2	64.4	54.8	41.2	27.9	15.8	4.9	0.3	.....	594	79	80	3
21-31	21.1	7 13	5.0	14.6	31.8	44.0	54.0	67.4	68.1	67.2	63.4	54.7	38.5	26.8	14.9	5.1	0.4	.....	556	73	65	6
June 1-10	22.6	7 19	6.4	18.5	32.8	43.8	53.7	64.4	66.6	67.7	59.0	53.2	39.5	25.2	14.3	5.8	0.6	.....	552	72	66	8
11-20	23.3	7 22	5.8	17.3	31.4	44.6	58.6	67.0	71.4	66.8	63.5	53.1	42.0	29.5	15.6	7.9	1.4	.....	576	75	67	7
21-30	23.4	7 22	5.9	14.7	29.8	44.7	56.2	64.5	63.2	63.2	49.8	40.0	37.0	23.5	13.7	7.6	1.2	.....	510	67	53	6
July 1-10	22.8	7 20	5.0	11.7	21.1	30.0	38.2	45.4	48.8	52.4	55.8	44.4	39.2	29.7	13.9	6.0	0.9	.....	443	60	46	8
11-20	21.5	7 15	3.6	12.4	24.2	34.4	44.4	58.3	57.8	62.7	60.2	48.5	43.0	29.8	20.4	10.4	1.1	.....	511	70	60	6
21-31	+19.5	7 07	3.7	15.9	30.9	43.0	50.9	59.2	60.8	64.1	62.2	47.9	34.2	27.3	17.3	6.2	0.5	.....	577	82	74	7
Aug. 1-10	16.9	6 57	2.6	11.5	22.2	34.9	45.4	51.9	49.9	54.8	51.9	44.0	33.5	25.4	16.4	5.2	0.4	.....	450	67	51	8
11-20	14.0	6 47	2.4	14.2	26.8	41.8	57.3	56.2	56.1	58.2	53.9	42.4	33.4	23.3	12.9	3.9	.....	.....	483	75	65	7
21-31	10.5	6 35	0.8	8.4	18.1	28.1	35.3	38.8	43.4	44.3	38.1	31.6	25.1	17.1	9.0	2.5	.....	.....	377	62	47	7
Sept. 1-10	6.8	6 22	0.8	9.3	22.0	36.9	46.3	54.8	56.4	63.6	61.9	48.4	37.1	25.6	14.4	2.1	.....	.....	480	84	75	5
11-20	3.0	6 10	0.1	5.5	14.7	27.0	37.6	41.6	44.3	47.6	47.4	40.5	32.5	16.9	9.2	1.0	.....	.....	366	68	60	6
21-30	− 0.9	5 57	.....	6.3	19.2	31.9	45.9	54.8	57.9	57.0	50.1	40.0	25.5	15.3	6.0	0.3	.....	.....	410	83	78	3

TABLE 10.—*Radiation extremes at Mount Weather, Va., expressed in gram-calories per square centimeter.*

Decade.	Mean solar zenith distance at noon.	Normal surface.	Horizontal surface.			
		Solar radiation.	Solar and sky radiation.			
		Maximum per minute.	Maximum per minute.	Maximum per hour.	Maximum per day.	Minimum per day.
1	2	3	4	5	6	7
1912.	° ′	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*
May 17-20	19 22	.....	1.63	82.8	655	370
May 21-31	17 57	1.27	1.57	88.3	723	312
June 1-10	16 28	1.41	1.63	90.5	748	427
June 11-20	15 45	1.32	1.61	87.2	670	91
June 21-30	15 44	1.25	1.52	83.6	633	122
July 1-10	16 21	1.21	1.56	82.8	683	377
July 11-20	17 39	1.21	1.62	91.9	759	217
July 21-31	19 40	1.19	1.60	86.7	693	75
Aug. 1-10	22 16	1.06	1.59	90.2	643	188
Aug. 11-20	25 12	1.13	1.56	76.4	497	308
Aug. 21-31	28 42	1.18	1.49	78.1	550	315
Sept. 1-10	32 29	1.18	1.50	71.2	525	250
Sept. 11-20	36 16	1.17	1.38	73.4	486	130
Sept. 21-30	40 09	1.19	1.33	68.5	480	50
Oct. 1-10	44 02	1.25	1.25	66.1	450	369
Oct. 11-20	47 48	1.34	1.17	61.6	416	207
Oct. 21-31	51 33	1.17	1.10	55.9	364	41
Nov. 1-10	54 55	1.25	1.09	49.0	303	35
Nov. 11-20	57 41	1.22	0.94	48.8	282	94
Nov. 21-30	59 55	1.22	0.87	46.5	249	138
Dec. 1-10	61 30	1.31	0.75	43.8	256	141
Dec. 11-20	62 21	1.24	0.89	43.0	247	41
Dec. 21-31	62 24	1.30	0.81	41.4	238	56
1913.						
Jan. 1-10	61 37	1.29	0.74	43.6	262	46
Jan. 11-20	60 06	.....	0.78	45.1	265	49
Jan. 21-31	57 47	1.30	0.88	47.0	292	28
Feb. 1-10	54 51	1.30	0.96	56.7	356	32
Feb. 11-20	51 35	1.33	1.11	59.5	379	124
Feb. 21-28	48 22	1.18	1.30	61.0	361	75
Mar. 1-10	44 58	1.23	1.32	73.4	479	91
Mar. 11-20	41 03	1.35	1.30	76.7	531	52
Mar. 21-31	36 54	1.40	1.47	78.9	569	91
Apr. 1-10	32 51	1.37	1.59	84.7	633	278
Apr. 11-20	29 10	1.41	1.50	88.3	705	46
Apr. 21-30	25 46	1.36	1.52	91.1	722	96
May 1-10	22 43	1.30	1.53	90.3	726	339
May 11-20	20 08	1.30	1.61	90.2	729	83
May 21-31	17 59	1.28	1.65	91.9	759	75
June 1-10	16 30	1.42	1.69	98.5	786	350
June 11-20	15 46	1.36	1.63	92.9	765	526
June 21-30	15 42	1.03	1.62	83.0	616	71
July 1-10	16 20	1.25	1.62	85.0	687	260
July 11-20	17 37	1.31	1.60	89.7	650	176
July 21-31	19 37	1.23	1.57	86.3	666	394
Aug. 1-10	22 12	1.30	1.44	82.8	636	253
Aug. 11-20	25 08	1.32	1.33	78.7	606	48
Aug. 21-31	28 37	1.41	1.41	81.4	607	149
Sept. 1-10	32 24	1.38	1.43	81.4	581	199
Sept. 11-20	36 11	1.35	1.41	73.7	531	72
Sept. 21-30	40 04	1.42	1.39	71.2	504	73
Oct. 1-10	43 56	1.37	1.33	65.8	463	62
Oct. 11-20	47 41	1.38	1.22	61.9	420	47
Oct. 21-31	51 28	1.22	1.25	57.6	375	18
Nov. 1-10	54 51	1.38	0.91	53.7	342	35
Nov. 11-20	57 38	1.32	0.99	47.7	292	32
Nov. 21-30	59 52	1.21	0.86	46.5	276	8
Dec. 1-10	61 28	1.30	0.96	45.7	260	29
Dec. 11-20	62 20	1.40	0.87	44.7	255	164
Dec. 21-31	62 24	.....	0.94	49.9	266	14
1914.						
Jan. 1-10	61 38	1.21	1.04	46.2	265	12
Jan. 11-20	60 08	1.29	1.09	50.1	288	93
Jan. 21-31	57 50	1.24	1.04	50.1	289	79
Feb. 1-10	54 55	1.42	1.11	65.0	405	24
Feb. 11-20	51 40	1.30	1.22	66.2	404	71
Feb. 21-28	48 28	1.46	1.38	81.4	517	85
Mar. 1-10	45 03	1.35	1.61	77.2	510	73
Mar. 11-20	41 08	1.48	1.53	83.6	578	90
Mar. 21-31	37 00	1.29	1.51	76.7	538	104
Apr. 1-10	32 56	1.35	1.56	83.0	643	50
Apr. 11-20	29 16	1.44	1.49	84.9	646	60
Apr. 21-30	25 51	1.43	1.55	86.3	693	80
May 1-10	22 47	1.28	1.65	88.6	716	169
May 11-20	20 11	1.31	1.52	85.8	705	178
May 21-31	18 02	1.39	1.56	88.0	726	356
June 1-10	16 31	1.39	1.52	88.3	716	280
June 11-20	15 46	1.46	1.60	90.5	783	93
June 21-30	15 42	1.41	1.54	88.3	759	216
July 1-10	16 20	1.38	1.56	87.8	724	135
July 11-20	18 34	1.40	1.52	88.3	716	279
July 21-31	19 34	1.38	1.66	83.6	659	303
Aug. 1-10	22 08	.....	1.53	77.3	562	334
Aug. 11-20	25 03	1.37	1.53	80.3	624	222
Aug. 21-31	28 32	1.30	1.48	77.3	570	74
Sept. 1-10	32 18	1.45	1.61	78.6	598	292
Sept. 11-20	36 06	1.42	1.49	73.2	498	48
Sept. 21-30	39 58	1.50	1.28	75.1	535	185

3. A table has been prepared from which the zenith distance of the sun can be readily determined at the time in each hour when half the radiation for that hour has been recorded.

4. Entering Table 8 with the zenith distance of the sun and the percentage of cloudiness as arguments, the factor F'_c is obtained, the product of which into the number of squares in each hourly area of the Calendar record multiplied by 10 gives the number of gram-calories of heat received during the successive hours per square centimeter of horizontal surface. These results have been tabulated, and the sums for the successive hours of each day taken, to obtain the total radiation received during the day. The decade averages for the successive hours and for the day are given in Table 9.

Daily extremes and averages of radiation.—In columns 6 and 7 of Table 10 are given the maximum and the minimum daily amounts of radiation, respectively, that have been recorded in each decade. The minimum daily amounts have been recorded on foggy days with rain, and the maximum daily amounts have usually been recorded on exceptionally clear days. The absolute maxima thus far recorded in each decade have been plotted in Trace I, figure 8. This trace, therefore, represents graphically the daily amounts of radiation that might be expected if the sky were continuously clear, or the *possible* daily radiation at Mount Weather, throughout the year. The "Percentage of possible radiation" in Table 9 has been obtained by dividing the "Daily average" given in that table by the possible daily radiation for the decade, obtained from Trace I, figure 8.

In Table 9 are also given the "Percentage of possible sunshine" derived from the records of the Marvin sunshine recorder, and the "Mean daily cloudiness" derived from the eye estimates entered in the "Daily Meteorological Record" already referred to.

In figure 8, traces II (+), III (○), and IV (●), are the plotted decade averages of daily radiation for the years 1912, 1913, and 1914, respectively. There are marked variations in these averages from decade to decade, principally on account of variations in the cloudiness; but there is no marked difference in the successive years. The depression in the intensity of direct solar radiation that culminated in August, 1912, is masked by the cloud effects in these plotted records of the total radiation. The percentage of possible radiation during the six months April to September, inclusive, has averaged 68 per cent, while for the remaining months it has averaged 63 per cent. The departures from these averages have not exceeded 1 per cent in any half-year period.

The percentage of possible sunshine during the above periods has averaged 55 per cent and 53 per cent, respectively.

In a previous paper (**13**) it has been shown that during the second half of 1912 the total radiation on clear days averaged from 3 to 5 per cent less than on clear days during corresponding months in 1913.

The absolute maximum daily amounts of radiation for the first and the second decades of June and the second decade of July were not recorded on clear days, but on days when there was some cloudiness which, while obscuring the sun but little, materially increased the radiation from the sky. Trace I, figure 8, for clear sky radiation, has therefore been drawn below the maxima for these decades. This trace shows that the total radiation per day per square centimeter of horizontal surface, with the clearest sky, varies from 250 calories on December 20 to 765 calories on June 10. On March 20 it is 605 calories

and 515 calories on September 20. In general, the radiation received on clear days during the half year December 21 to June 20 exceeds that received on clear days during the half year June 21 to December 20, by about 8 per cent. This is principally because of the increased water vapor content of the atmosphere during the latter period.

Maximum radiation per minute and per hour.—In column 3 of Table 10 is recorded the maximum solar radiation measured by the Marvin pyrheliometer in each decade, extrapolated to the noon hour unless there is evidence that the sun was obscured by clouds at noon on the day when the highest readings were obtained. Usually the extrapolation was for a few minutes of time only, and for not more than 0.01 or 0.02 gram-calorie of radiation.

The maximum radiation per minute recorded in column 4 of Table 10 has been taken from the Callendar records. In nearly every case the record was made when clouds surrounded the sun but did not obscure it. Reproductions of records obtained under such conditions will be found in the Bulletin of the Mount Weather Observatory, vol. 5, pages 169–171. In reducing these records to heat units equation (2), page 480, for F'_o, has been employed.

The maximum radiation per hour given in column 5 of Table 10 has been recorded in most cases during the hour just preceding or following noon on a day with an unusually clear sky.

In figure 9, Trace I(+), represents the absolute maxima of solar radiation at normal incidence, based on the pyrheliometric measurements made at Mount Weather since September 21, 1907. Trace II(○), represents the absolute maxima of radiation on a horizontal surface, based on the data in column 4 of Table 10. Trace III (●), represents the extreme hourly maxima of column 5, Table 10, reduced to minute rates. It therefore gives the absolute maxima of radiation on a horizontal surface when the sky is free from clouds. The actual maximum measurements for each decade are indicated by crosses or circles in connection with the respective traces.

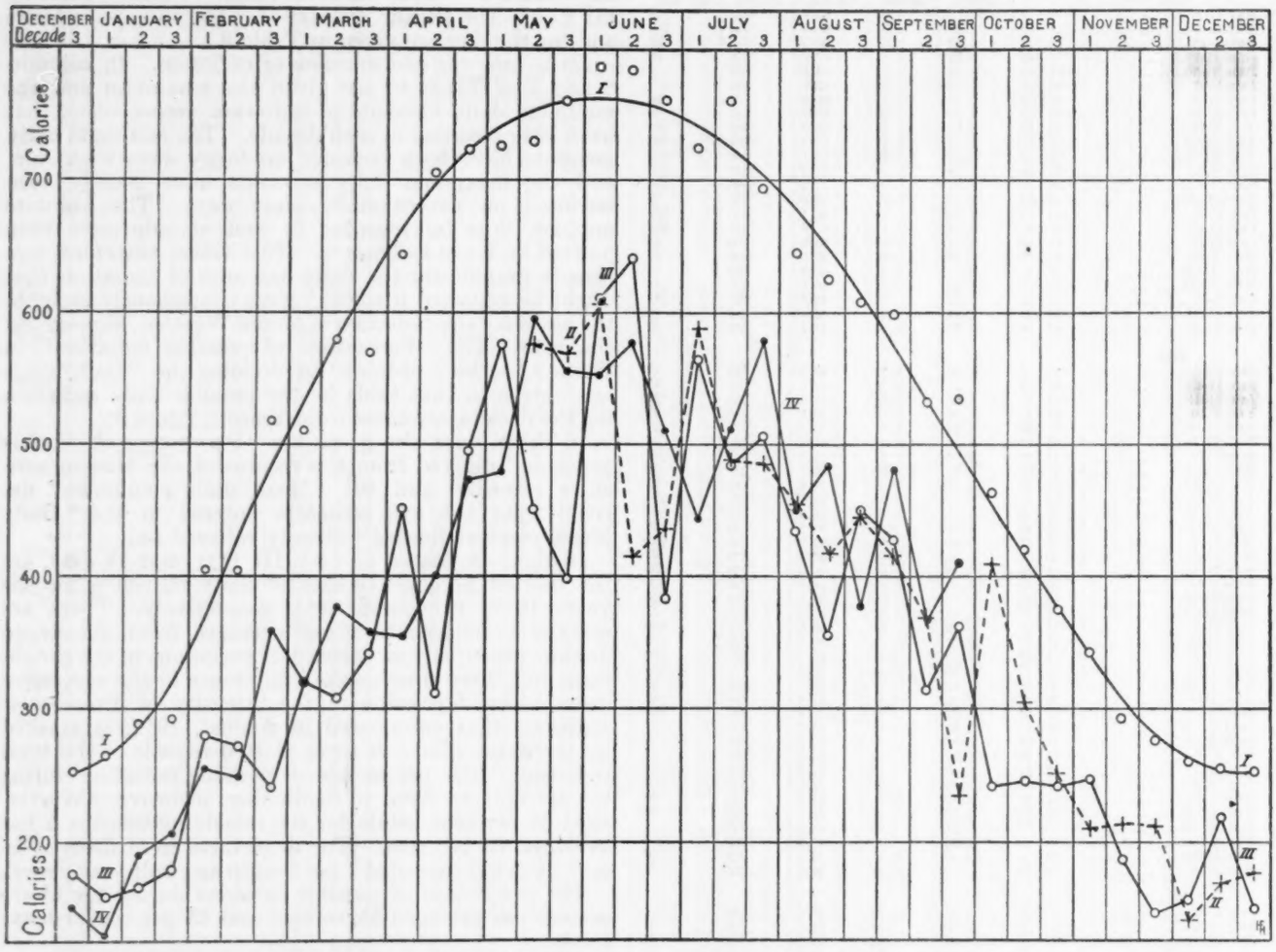

FIG. 8.—Maximum and average daily amounts of radiation for each decade. I, maximum; II (+), III (○), and IV (●), averages for 1912, 1913, and 1914, respectively.

Trace I for maximum radiation at normal incidence shows but little annual variation. A rate of 1.40 calories per minute per square centimeter has been recorded in every month except January, and a rate of 1.45 calories, or above, in every month from February to October, inclusive, with an extreme of 1.50 calories in May and September. The maximum for January is 1.37 calories. The smallness of this range is accounted for by the fact that in winter, when the sun's zenith distance at noon is a maximum, its distance from the earth, and the dust and water vapor content of the earth's atmosphere, are at a minimum.

Trace III shows that when the sky is free from clouds the maximum radiation per square centimeter of horizontal surface ranges from 0.77 calorie per minute in

December to 1.55 calories in June. It is twice as great in June as in December, as we would expect, since in December, with a zenith distance of the sun of about 62°, the vertical component of the solar radiation is only 47 per cent of its intensity at normal incidence, while in June with a zenith distance of the sun at noon of about 16° it is nearly 97 per cent.

Trace II shows that cloud reflection increases these intensities on a horizontal surface by about 0.15 calorie. Thus, in December the maximum is about 0.93 calorie, and in June it is about 1.65 calories, with one observation showing 1.69 calories. Both traces II and III show that the rates during the half year December 21 to June 20 average about 8 per cent higher than during the half year June 21 to December 20, as is the case with the maximum daily rates plotted in figure 8, trace I.

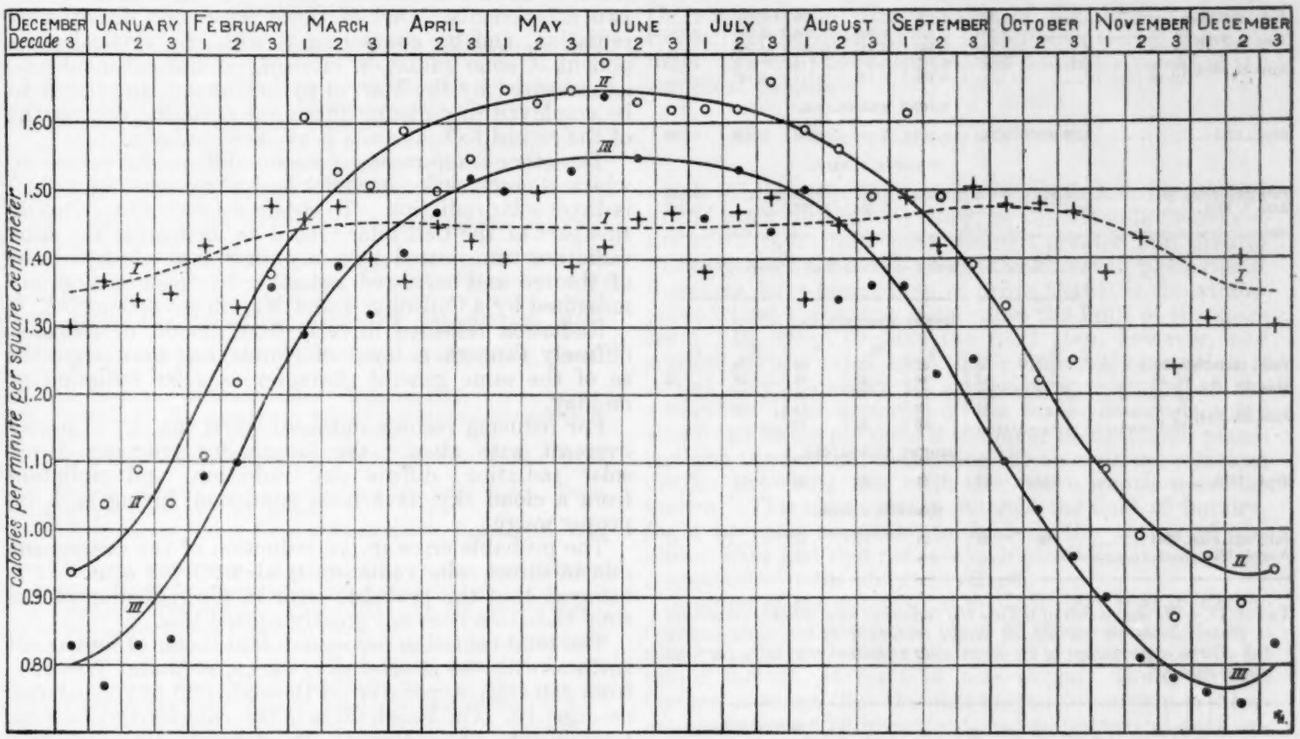

FIG. 9.—Maximum radiation per minute. Curve I (+), normal incidence; II (○), horizontal surface, with clouds near the sun but not obscuring it; III (●), horizontal surface, with cloudless sky.

It is of interest to compare the maximum rates of radiation given above with those obtained at the Transvaal Observatory, Johannesburg, latitude 26° 11′ south, altitude 5,925 feet (**14**). The Callendar pyrheliometer records give a daily maximum of 748 calories per square centimeter of horizontal surface, in December and January, and a maximum rate per minute in November of 1.71 calories. The maximum rate per minute as measured by the Ångström pyrheliometer is 1.61 calories per square centimeter of normal surface, and it occurred in January. The statement is made that the Ångström instrument has been employed to standardize the Callendar pyrheliometer, but the method of standardization is not given (**15**). The smallness of the excess of the maximum rates of radiation obtained from the Callendar records for Johannesburg over those for Mount Weather is probably due to the difference in the methods by which the instruments in use at the two observatories have been standardized.

At South Kensington, England, the maximum radiation per minute recorded by a Callendar pyrheliometer in 1911 was 1.33 calories per square centimeter (**16**).

Diffuse sky radiation.—In Table 11 are summarized measurements of diffuse radiation from the sky, expressed in gram-calories per minute per square centimeter of horizontal surface in the first part of the table, and as a percentage of the direct solar radiation received on a horizontal surface in the second part of the table. The data in the first line for Mount Weather have been obtained from Table 7, and represent average clear-sky conditions. The data for May 20 and June 30, 1914, have been taken from the record sheets reproduced in figure 7. May 20 was a cloudless day, but unusually hazy. The sky on June 30 was unusually clear, except that it was about two-tenths covered with cumulus clouds in the afternoon. On May 20, 32 per cent of the total radiation received during the day on a horizontal surface was diffuse sky radiation, and on June 30, 13 per cent. Or, on May 20 the diffuse sky radiation was 47 per cent of direct solar radiation, and on June 30 it was 15 per cent.

For purposes of comparison there have been added to Table 11 measurements made by Abbot on Mount Wilson, Cal., with a bolometer (**17**), and by Patterson at Toronto, Canada, with a Callendar pyrheliometer (**4**). The first line for the latter represents the mean of observations on three days with a clear sky. The second line represents the results of observations on a very hazy day.

If the Toronto measurements expressed in calories are divided by the factor 0.81 (see method of determining F_1, page 480), they are brought into accord with the Mount Weather measurements.

The Mount Wilson measurements are higher than we would expect from the results obtained at Mount Weather and Toronto. We may, however, compare these with

earlier measurements by Abbot (18), summarized in Table 12, most of which were made near midday.

TABLE 11.—*Measurements of diffuse sky radiation at different stations (expressed in gram-calories per minute per square centimeter of horizontal surface, and also as a percentage of the direct solar radiation received on a horizontal surface).*

Date.	Altitude of sun. 5°	15°	25°	35°	47½°	65°	Noon.
	Gr.-Cal.	Gr.-Cal.	Gr.-Cal.	Gr.-Cal.	Gr.-Cal.	Gr.-Cal.	Gr.-Cal.
MOUNT WEATHER, VA.							
Feb., 1913–Feb., 1914	.....	0.103	0.135	0.167	0.209	0.260	.....
May 20, 1914. a. m.	.....	0.144	0.222	0.249	0.306	0.330	0.333
May 20, 1914. p. m.	.....	0.118	0.180	0.237	0.291	0.348	.....
June 30, 1914. a. m.	.....	0.087	0.102	0.108	0.114	0.153	0.153
June 30, 1914. p. m.	.....	.....	0.150	0.126	0.114	0.147	.....
MOUNT WILSON, CAL.							
Sept., 1913	0.056	0.110	0.162	0.189	0.205	0.226	0.240
TORONTO, CANADA.							
July and Aug., 1911	0.042	0.076	0.100	0.113	0.118	.....	0.115
Aug. 1, 1911	.....	.....	.....	0.235	0.272	.....	0.265
	Ratio, sky/solar, expressed as a percentage.						
MOUNT WEATHER, VA.							
Feb., 1913–Feb., 1914	%	% 52	% 32	% 25	% 24	% 24	% .....
May 20, 1914, a. m.	.....	147	86	45	46	38	36
May 20, 1914, p. m.	.....	131	76	43	44	40	.....
June 30, 1914, a. m.	.....	35	20	14	11	12	11
June 30, 1914, p. m.	.....	.....	36	19	12	.....	.....
MOUNT WILSON, CAL.							
Sept., 1913	122	47	31	24	20	17	16
TORONTO, CANADA.							
July and Aug., 1911	66	31	24	19	15	.....	11
Aug. 1, 1911	.....	.....	.....	70	53	.....	45

TABLE 12.—*Measurements of diffuse sky radiation near midday (expressed in gram-calories per minute per square centimeter of horizontal surface and also as a percentage of the direct solar radiation received on a horizontal surface).*

Station.	Date.	Sky radiation. Gr.-cal. min./cm².	Percentage of solar.
Mount Wilson, Cal. (1730 m.)	Aug. 18, 1905	0.081	6
	Sept. and Oct., 1906	0.108	12
Mount Whitney, Cal. (4420 m.)	Aug. 17, 1910	0.127	8
Flint Island, South Pacific	Dec. 29, 1907	0.358	28
Bassour, Algeria (1160 m.)	Sept., 1912	0.245	23

Taking into account the respective altitudes, the bad sky conditions that prevailed at Flint Island, and the hazy condition of the sky at Bassour in September, 1912, it appears that the measurements of diffuse sky radiation made at Mount Weather fall well within the limits of measurements made at other stations with both similar and with very different apparatus.

I wish to acknowledge my indebtedness to my associates for many valuable suggestions during the progress of this investigation, and especially to Prof. Wm. R. Blair, with whom originated the scheme employed for reducing the intensity of solar radiation by different amounts; to my assistant, Mr. Irving F. Hand, who has made nearly all of the observations with the Marvin pyrheliometer, and has done most of the computing connected with the reduction of the records; and to the mechanician, Mr. A. J. Weed, who has introduced modifications and improvements in apparatus employed. Also to the United States Bureau of Standards for experimental work in determining the character of color screen to be employed and for the loan of the screen.

SUMMARY.

By using, in connection with the Callendar pyrheliometer, a screen that eclipses the sun at intervals throughout the day, the record of the total radiation received upon a horizontal surface has been divided into two components. One of these represents direct solar radiation, and by comparing it with the vertical component of solar radiation intensity at normal incidence, as measured by the Marvin pyrheliometer, the factor to be employed in reducing this solar radiation component of the record to heat units is at once obtained.

The other component represents diffuse sky radiation, which is much richer in violet and ultraviolet light than is direct solar radiation. To obtain the factor for reducing this part of the Callendar record to heat units the solar radiation transmitted by a ray filter that absorbs most of the red and infra-red radiation has been alternately measured by a Callendar and a Marvin pyrheliometer.

Radiation reflected directly from clouds, or reflected diffusely through a layer of clouds, has been regarded as of the same general character as solar radiation at midday.

For reducing records obtained when the sky is partly overcast with clouds, the factors for reducing direct solar radiation, diffuse sky radiation, and radiation from a cloud sky have been combined, giving each its proper weight.

The probable error in the reduction of the component due to direct solar radiation is about 3 per cent. It is believed that the probable error in the reduction of the total radiation does not greatly exceed this.

The total radiation per square centimeter of horizontal surface, with the clearest sky, varies, at Mount Weather, from 250 calories per day on December 20 to 765 calories on June 10. On March 20 it is 605 calories and on September 20, 515 calories. In general, the radiation received on clear days during the half-year December 21 to June 20 averages about 8 per cent more than that received during the half-year June 21 to December 20. The average daily radiation in summer is about 68 per cent of that received on clear days, and in winter it is about 63 per cent.

The maximum solar radiation at normal incidence varies from 1.37 calories per minute per square centimeter in January to 1.50 calories in May and September. The total radiation on a horizontal surface with a clear sky varies from 0.77 calorie per minute in December to 1.55 calories in June. When clouds are near the sun, but do not obscure it, the momentary maximum rates are increased by about 0.15 calorie.

The diffuse sky radiation received on a horizontal surface at noon averages about 25 per cent of that received on the same surface from the sun. On a clear summer day it amounts to from one-eighth to one-third of the total radiation.

Expressed in units of work, the receipt of one calorie of heat per minute per square centimeter of area represents 697 watts per square meter, or 0.78 horsepower

per square yard; and 1.50 calories per minute, or 90 calories per hour, which is not an uncommon rate at midday in summer with a clear sky, represents over 1 kilowatt per square meter, or nearly 1.2 horsepower per square yard. The radiation received on a square meter of horizontal surface during a clear day in midsummer is equivalent to 5 kilowatt-hours; and a daily total per square centimeter of 600 calories, which is equalled or exceeded at Mount Weather on clear days from the middle of March to the end of August, is equivalent to 4 kilowatt-hours per square meter. The daily average at this season of the year, including all kinds of weather, is about two-thirds of that for clear weather.

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THE ABSORPTION OF THE ATMOSPHERE FOR ULTRA-VIOLET LIGHT.

By Prof. THEODORE LYMAN.

[Dated: Jefferson Physical Laboratory, Harvard University, Sept. 21, 1914.]

The absorption of the air, to which this article is devoted, manifests itself in two regions of the ultra-violet and is of particular interest to two classes of observers. The first region lies at the less refrangible end of the ultra-violet where glass is no longer transparent; the second region is the extreme ultra-violet where even quartz loses its transparency and where the ordinary photographic plate is no longer sensitive. It is the first region that is of interest to the meteorologist and to the student of cosmical phenomena, since it is here that atmospheric absorption influences the light we receive from celestial bodies. It is the second which is chiefly of importance to the pure physicist.

The absorption of the atmosphere in the first region finds its most striking illustration in the abrupt termination of the solar spectrum in the ultra-violet. If the light from the sun is examined by means of a quartz spectroscope, the spectrum is found to terminate rather abruptly near wave-length 3,000 Å. U.,[1] while if the spectrum of the iron spark or arc is examined, it is found to extend to near wave-length 2,000. That the difference in extent of the spectra from celestial and terrestrial sources depends on the difference in the thickness of the medium which produces the absorption is a fairly obvious hypothesis, but it was only after Cornu had put the matter to experimental test that the hypothesis was regarded as definitely established.

Cornu's first experiments consisted in observing the limit of the solar spectrum at different hours of the day. He observed that the position of this limit retreated toward the less refrangible region with decreasing altitude. He was able to express his results by means of the empirical formula—

$$\text{Sin } \theta = 0.49 \times \varepsilon^{-0.0833(\lambda - 300)}$$

which exhibits the limiting wave-length λ in its relation to the sun's altitude θ. Now, as the altitude decreases, the sun's rays must pass through greater and greater thicknesses of the atmosphere; the observed phenomena, therefore, have been taken to prove that it is the atmosphere whose absorption determines the limit of the spectrum. In order to take the next step, however, and account for the exact form of the empirical expression, it is not only necessary to express the thickness of the absorption layer in terms of the sun's altitude, a thing which can be simply done if the layer is considered plane, but also the relation connecting the absorption coefficient of the absorbing gas with the wave-length must be known. This considerably extends the field of inquiry, for it becomes necessary to analyze the action of the atmosphere and determine which of its constituents are responsible for the observed effects.

A study of the subject has made it clear that it is sufficient to fix the attention upon oxygen and ozone since nitrogen and the other constituents do not appear to be major factors, at least in this region. Going a step farther, it seems that the part played by oxygen is interesting, and may be important, but as numerical data are lacking, it will be well to consider first the action of ozone for which the necessary figures are at hand.

Hartley(1) suggested some time ago that as ozone was known to possess a strong absorption band in that part of the ultra-violet where the sun's spectrum ends, the action of the atmosphere might be ascribed to the ozone which it contains. Recently, Fabry (2) and Buisson have measured the absorption coefficient α, as defined by the equation $I = I_0 10^{-\alpha d}$, over the region between wave-lengths 3,500 and 2,200 and have applied their results to explain the form of the empirical relation of Cornu with which we are at present concerned. To this end they have plotted the logarithm of the absorption coefficient against the wave-length. The graph of this function is a straight line between wave-lengths 3,500 and 2,800. If this relation is combined with the expression connecting the thickness of the absorbing layer with the zenith distance, Fabry showed that an expression of the same form as the empirical equation of Cornu results. In fact, not only is the form the same but the numerical constants are nearly identical.

[1] The Ångström unit of wave length is 10^{-10} meters and is usually abbreviated Å. U.—[C. A., Jr.]

The net result of all this is that if we confine our attention to the relation connecting the thickness of the absorbing layer and the limit of the solar spectrum as found by Cornu at a single point on the earth's surface, the facts may be completely explained on the assumption that the active agent is the ozone in the earth's atmosphere. It is extremely important to observe that this conclusion does not depend on the distribution of the ozone in the atmosphere but only on the total amount of the gas between the observer and the sun. As we shall see presently we have reason to believe that the total amount as determined experimentally is sufficient to account for the facts.

The difficulties of the subject only become manifest when we attempt to follow Cornu in those experiments where he varied the thickness of the absorbing layer, not by observing the sun at various altitudes but by changing the altitude of the place of observation. In order to predict the manner in which the limit of the spectrum should vary with the altitude of the observer for constant altitude of the sun, it is obviously necessary to introduce a new hypothesis into the calculations. Cornu assumed that each cubic meter of the atmosphere contains the same per cent of the absorbing gas, and that the density of the atmosphere varies with the altitude according to the barometric law. He was thus led to a simple expression whose fundamental constant implicitly contained, among other factors, the relation between the absorption coefficient of the gas and the limiting wave length. The expression predicted that for every rise of 896 meters the spectrum should extend itself by 10 Ångström units.

By making observations with the sun at the zenith at various altitudes on the earth's surface, Cornu obtained values for the last visible wave length which were in fair agreement with those yielded by his formula.

These simple and satisfactory conclusions have recently been rather upset by the work of Miethe and Lehmann (3) and the observations of Wigand (4). The first mentioned observers found that if they concentrated their attention on the last trace of light action recorded on the photographic plate the position of this impression did not alter at all as the altitude was varied by 4,500 meters. Wigand extended the scope of the experiment by taking the spectroscope of Miethe and Lehmann to an altitude of 9,000 meters in a balloon. He found the position of the last trace of light action was the same at this great altitude as on the earth's surface at Halle. It occurred at wave length 2,897. These results appear to flatly contradict those of Cornu since they show that the limit of the solar spectrum is independent of the altitude of the observer. As a matter of fact, the conclusions of the German observers, though sufficiently perplexing, are not absolutely in contradiction with those of Cornu for Wigand and his countrymen actually measured the position of the last trace of photographic effect on the plate while Cornu's observations probably deal rather with the change in the intensity of the spectrum very near the limit; the imperfection of his apparatus did not permit him to detect the limit itself (4). It appears, therefore, that Cornu's experimental results are not to be discarded as wholly wrong; they represent part of the truth but not the whole truth. His simple formula, however, is obviously only an approximation of very limited range.

If the work of Miethe, Lehmann and Wigand is to be accepted, it is certainly impossible to ascribe the limit of the solar spectrum to the absorption of a gas uniformly distributed in the atmosphere. Now Cornu's data on the variation of the length of the solar spectrum at different times of day agree so well with Fabry's experiments on the absorption of ozone that one is loath to abandon the idea that this gas is an important factor in the phenomenon. One is naturally led to ask, therefore, if the gas can be distributed in the atmosphere in a manner which will account for the fact that the extreme limit of the spectrum is independent of the altitude of the observer while the distribution of intensity very near this limit varies with the altitude of the sun. In other words, have we any evidence to show that the concentration of ozone increases very rapidly in the atmosphere above 9,000 meters?

There are serious discrepancies among the results of various observers of the ozone content at moderate altitudes, and data as to the variation of the ozone content of the air over a considerable range of altitude are, as yet, rather meager. The results of Pring (5) are the most recent. He finds by experiments on the earth's surface that the ozone concentration of the air is 2.5×10^{-6} at 2,130 meters and 4.7×10^{-6} at 3,600 meters. The average of 10 sets of data obtained by sending up the apparatus in balloons to altitudes from 6 to 20 kilometers gave a value of 2.1×10^{-6} for the concentration. Furthermore, he calculates that if every cubic meter of air between the earth and the sun contained the same per cent of ozone which he finds experimentally at 3,600 meters, the gas layer would be equivalent to a thickness of pure ozone of 4.2 cm. at atmospheric pressure. Fabry has calculated from his observations that a layer of pure ozone 5 mm. thick would account for the limit of the spectrum as observed by Cornu at sea level. Pring's measurements, therefore, substantiate the claim of Fabry that ozone is the active agent in Cornu's results but they do not give evidence of the increased concentration in the upper atmosphere indicated by the observations of Wigand.

The whole question of the distribution of ozone at very high altitudes is still one worthy of the attention of experimenters. Pring's values for any one altitude were obtained by averaging data which vary over rather wide limits. His conclusions are of extreme importance, but it would be well to confirm them by a series of observations at some of the highest practicable points on the earth's surface.

The data at hand give us no right to assume that the absorption of ozone alone will account for the behavior of the atmosphere as indicated by the extent of the solar spectrum. Even the simplest phenomenon, however, is the result of a number of causes, so here the observed absorption is probably due to more than one agent. We have neglected the effect of nitrogen and of the impurities in the atmosphere such as carbon monoxide and water vapor, for such data as we have on the subject point to the fact that these agents are relatively unimportant in the particular part of the spectrum which we are studying. It must not be forgotten, however, that we know very little about the absorption of these substances in columns of the length which enter into the problem.

The action of oxygen is a matter which can not be neglected, but though its behavior in the extreme ultraviolet is pretty well understood, as we shall see presently, very little is really known about its behavior in the region where the solar spectrum ends. Liveing (6) and Dewar as long ago as 1888 tried to imitate the mass of oxygen which occurs in the atmosphere between the earth and

the sun bycompressing the gas in a tube 18 meters long to a pressure of 90 atmospheres. Their results showed a stronger absorption of oxygen than would be required to account for the termination of the solar spectrum at wave-length 3,000; with the path length and pressure just mentioned the column of gas absorbed everything on the less refrangible side of wave-length 3,100. The observers were led to believe that their tube gave more absorption than the earth's atmosphere, for some of the bands in the less refrangible part of the spectrum were more intense in their experiment than when seen in the solar spectrum.

The accuracy of the imitation of the earth's atmosphere depends on the assumption that if the product of the pressure and path length of a gas remains constant the absorption of the gas remains constant; this hypothesis, known as Beer's Law, seems to hold for most gases throughout the visible part of the spectrum; it does not hold for gases in the infra-red. There seems some reason to believe from the work of Jannsen that it does not hold for part of the oxygen spectrum even in the visible. Be this as it may, it seems improbable that the departure from Beer's Law could do more than slightly modify the phenomenon observed by Liveing. It becomes evident, therefore, that the absorption of oxygen may be an important factor in the question under discussion. Unfortunately, no data exist for oxygen similar to that obtained by Fabry for ozone connecting the coefficient of absorption with the wave-length in the region of the ultra-violet. Until such evidence is forthcoming, the exact part played by oxygen in determining the limit of the solar spectrum will be unknown. We can say with some certainty, however, that as oxygen does not occur concentrated in the atmosphere at very high altitudes, it cannot be the cause of the phenomena observed by Wigand.

The treatment of the absorption of the atmosphere would not be complete without some mention of the part played by scattering. The predictions of Rayleigh and Schuster (**7**) have been admirably verified by Abbot (**8**), but the nature of the scattering action is such that it does not pretend to account for the abrupt termination of the solar spectrum near wave-length 3,000. The suggestion of Wigand that scattering at altitudes above 9,000 meters is an important factor does not seem tenable.

There is still one way of escape from the difficulty introduced by the observations of Miethe and of Wigand. If the sun itself sent out no light of a wave-length shorter than the limit obtained by these observers, the independence of this limit with altitude would be explained. That the sun's radiation terminates abruptly does not seem probable, but it may rapidly decrease in intensity with decreased wave-length in the ultra-violet. In this connection, data on the extent of stellar spectra would be of great interest. As far as I am aware, experiments of this type with quartz apparatus are still lacking. Moreover, experiments on the absorption of very long columns of air for light from a terrestrial source could not fail to give very important results.

I have treated the second region of ultra-violet absorption, mentioned at the beginning of this article, rather exhaustively in a forthcoming monograph in Sir J. J. Thomson's Series published by Longmans (**9**), so a very brief résumé will be sufficient here. The part of the spectrum in question lies on the more refrangible side of wave-length 1,900 and is known as the Schumann region. Here oxygen is the dominating factor; it begins to absorb strongly near wave-length 1,850. So intense is this action that a few millimeters of the gas completely cut out any light near wave-length 1,600. The gas partially regains its transparency near wave-length 1,300, but even here the light transmitted is very feeble. The present limit of the spectrum obtained from a concave diffraction grating lies near wave-length 900.

Very little is known of the absorption of oxygen between the region near wave-length 1,900 and the part of the spectrum where light from the sun ceases to reach us. The absorption observed by Liveing and Dewar may be the manifestation of the shoulder of the same absorption band which begins to rise so rapidly at the beginning of the Schumann region. On the other hand, oxygen may have two absorption bands in this region with a place of relative transparency between. If this second hypothesis is the correct one, it gives rise to a rather interesting speculation. For since ozone is known to regain its transparency near wave-length 2100 it is just possible that light from the sun of this latter wave length may reach us feebly, provided that the oxygen is sufficiently transparent at this point, and provided, also, that the sun gives out light of the required refrangibility. Meyer (**10**) looked for this "hole in the atmosphere" but he was unable to find it. However, since his experiments, the technique of observation has been considerably improved; it might be worth while to look again.

In conclusion, it is well to remember the debt we owe to the atmosphere as a protective agency. The bactericidal action of light is well known in the visible part of the spectrum, but the fact that this action suddenly increases many hundredfold at a given point in the ultra-violet is perhaps not quite so familiar. The following experiment performed by Prof. R. W. Wood, and which I have often seen repeated, illustrates this point. A glass plate coated with nutrient agar-agar is sprinkled with *Bacillus prodigeosus* and is exposed in a quartz spectroscope to the light from an iron spark. The plate is then removed and is maintained in a suitable moist atmosphere and at proper temperature. The growth of the bacillus is hardly affected by the light in the visible part of the spectrum but when a definite point in the ultra-violet is reached no growth occurs. The light has killed the bacillus. Now this point where the killing action becomes evident is the same for a great number of microscopic organisms and, what is most important, it lies but very slightly on the ultra-violet side of the point where the atmosphere cuts off the solar spectrum. As the abiotic action is by no means confined to pathogenic organisms, it is evident that the absorption of the air protects human beings from most unpleasant consequences.

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(10) **Meyer** *in* Annalen der Physik, 1903, **12**: 849.

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SECTION II.—GENERAL METEOROLOGY.

THE EXUDATION OF ICE FROM STEMS OF PLANTS.

By WM. W. COBLENTZ.

[Dated: United States Bureau of Standards, Washington, D. C., July 10, 1914.]

INTRODUCTION.

Nocturnal radiation is generally a passing of radiant energy from terrestrial substances into space. On a clear night the rate at which radiation passes outward from a lampblack surface is very great, amounting to almost one-tenth of the solar constant. Of course not all substances lose heat at this rate. This loss of heat by radiation produces peculiar formations of ice, some of which will now be mentioned.

Ice columns.—The most familiar freak of ice formation occurs on bare, clayey soils which contain a certain (minimum) amount of moisture. If the moisture content of the soil falls below this minimum value (which no doubt varies for different soils) then evaporation occurs as rapidly as the moisture is brought to the surface (by capillary action) and no ice is formed. According to the writer's observations the ice is formed in contact with a nucleus which may be a grain of sand, a small pebble, etc. The earthy material has a higher emissivity than the water, it cools more rapidly and the water freezes on the under side of the nucleus. As heat is lost more ice is formed and, as it accumulates, rises in the columns often to be observed everywhere on cold mornings [and technically known as ice columns or columnar ice]. The water is supplied by capillary movement in the soil, from the surface of which the ground ice may be readily lifted, since in freezing weather the ice is not frozen into the soil (1). The general experience is to find the ground ice supporting a nucleus (say a grain of sand, or even large stones, $3\times1\frac{1}{2}\times1$ inch in size). The nuclei may be thinly distributed. The writer has observed several large areas, $3\times1\frac{1}{2}$ feet, which did not contain nuclei, whence it appears that this type of ice formation can occur without having a nucleus (gravel, etc.) to start the refrigeration.

Anchor ice.—Barnes (2) has made a prolonged study of the formation of "anchor ice" on the bottom of the St. Lawrence River and frazil or anchor ice within the flowing water itself. This kind of ice consists of fine spicules which adhere to the bottom of the river. It forms friable masses which may vary from 6 to 8 feet in thickness. According to Barnes, this ice is formed as a result of the greater emissivity and hence the greater cooling of the material composing the river bottom.

Hoar frost.—Another example of ice formation as the result of cooling by radiation is the form called hoar frost. Here, however, the accepted explanation is that the ice spicules are formed by accretion, as the result of the deposition of moisture from the surrounding air.

The foregoing are familiar and interesting illustrations of ice formations on substances as the result primarily of the loss of heat by radiation. We have now to consider a rarer phenomenon, which is the subject of the present paper.

ICE FORMATIONS ON PLANTS.

According to the writer's observations the amount of ice formed upon a plant stem is a function of— (1) The rate at which water can rise by capillary action in the sap tubes within the stem; (2) the ease with which the moisture can pass out to the surface; (3) the rate of evaporation from the surface (convection, wind velocity); and (4) the emissivity of the surface of the stem. Instead of the title "Exudation of ice" a more pretentious title would have been "The capillary movement of water—An experimental demonstration by means of the formation of ice fringes on plants." This might appear more scientific, and one could discuss the capillary movement of water as a function of the temperature of the stem; the size of bore and number of sap tubes; the thickness and permeability of the walls of these tubes, etc. However, the present communication makes no pretense at such completeness of the investigation. In fact, the subject of ice formation forced itself upon the writer at a time when other duties were pressing, and hence it could not be given the attention it deserved. As a result, the experimental tests, to be described presently, were usually carried out only to the extent of refuting the various notions held by various persons as to the cause of this ice formation. All sorts of explanations were presented. This is the main reason for giving in extenso these simple tests which show that the formation of fringes of ice on plant stems is not the result of accretion, hydrostatic pressure, rifts in the stem, moisture in the bark, the presence of sap, etc., but that it is the result primarily of the capillary movement of water in the numerous sap tubes which are to be found in those plant stems upon which the ice formations are the most conspicuous.

Historical data.

One of the earliest descriptions of the exudation of ice fringes from plants was published by Herschel (3) about 80 years ago. His observations relate to the icy fringes which were formed around thistle stalks and stumps of heliotropes, many specimens of which were still green. Stephen Elliot (4) had previously described a remarkable protrusion of fringes of ice from the stems of flea bane (*Conyza bifrons*).

The fullest account, with an attempted explanation of this phenomenon, was given by John Le Conte (5) about 63 years ago. His observations are on two species of flea bane, *Pluchea bifrons* and *Pluchea camphorata*, which he found growing in wet soils, around ponds, and along roadside ditches in the lowlands of South Carolina and Georgia. In these plants the root is perennial, but the stem is annual and herbaceous.

Le Conte's descriptions differ materially from my own. His observations appeared to establish the following facts in relation to the phenomenon:

1.

The depositions of ice are entirely confined to the immediate neighborhood of the roots of the plants, the upper parts of the tall unbroken stalks being quite free from them. They frequently com-

mence 2 or 3 inches from the ground and extend from 3 to 4 inches along the axis of the stem. The stalks are dead and quite dry to within about 6 inches of the earth, below which they are generally green and succulent. The plant has a large and porous pith, which is always saturated with moisture as high as 6 or 7 inches from the base of the stem.

From this it would appear that the ice was formed on the green stems, as was true of many of the specimens of heliotrope described by Herschel.

2.

The ice emanates in a kind of riband, or frill-shaped, wavy, friable, semipellucid excrescence, the structure of which (quoting Herschel) is "fibrous, like that of the fibrous variety of gypsum, presenting a glassy, silky, wavy surface; the direction of the fibers being at right angles to the stem, or horizontal."

Le Conte found that the number of ribands varied from one to five, which issued from the stems in vertical or longitudinal lines, often unsymmetrically displayed around the axis. He frequently observed the icy excrescences to exceed 5 inches in length; often curled back so that the remote extremity of the frill came close to the line of attachment to the stalk.

From this it may be noticed that the amount of ice formed is very considerable. Evidently the moisture must come from within the plant. The amount of water congealed during a single night is vastly too great to come from the aqueous vapor in the atmosphere; hence the phenomenon can not be a modification of hoarfrost. In fact, in the illustrations to be cited presently, which were observed by the writer, the excrescences of ice on one particular species of plant were formed every night that was sufficiently cool for ice formation, although there was little or no formation of hoarfrost anywhere in the vicinity.

3. Although the ice sheets appeared to protrude from the interior of the stem, both Herschel and Le Conte found that usually the stems were solid and that the ice terminated at the surface. "The point of attachment of the ice was always the wood, beneath the outer bark or epidermis, which the frozen sheets had in every instance stripped off and forced out to a distance." When the frost was severe Le Conte found that the ice riband was continuous with the frozen pith through a longitudinal rift in the woody stem.

4. Le Conte found that—

The phenomenon took place in the same plant during several consecutive nights, and, when the wood was not rifted, frequently from the same portion of the stalk. When the wood was split, however, the deposition of ice occurred lower down the stem at a part which was unaffected by the frost of the previous night. The stalks thus became completely rifted by a succession of severe nights from the height of 6 or 7 inches down to the ground. This is unquestionably one of the reasons why these exudations of ice are seldom observed after the middle of the winter, for the stalks are usually destroyed before this period.

Le Conte considered the ice formation on plants to be a physical phenomenon, having no connection with the vitality of the stem. His explanation of the ice formation was that the moisture from the pith passes out along the wedge-shaped medullary rays which are to be found in abundance in this plant, and is frozen on the outside of the stem. He considered that the wedge-shaped medullary rays exerted a "projectile force" which brings the moisture to the surface. The exudation of ice columns from the earth he referred to the same cause, viz, a rapid and forcible expansion, along capillary tubes.

To the writer it does not appear necessary to postulate a complex "projectile force" to explain the ice fringes on plants. In fact, the plants upon which ice is formed in the greatest abundance have a preponderance of sap tubes, only an insignificant part of the stem being occupied by medullary rays.

Ward (6) has given a rather popular description of the occurrence of ice fringes. He describes the fringes as projecting out horizontally, "not straight and stiff, but gently and gracefully curving or coiling into a beautiful conch-like roll at the distal end." His observations were probably of short duration, otherwise he would have found but few instances in which the "fringes are attached at regular intervals around the stem, like paddles of a turbine wheel." He found that the bark was split into strips at the zone occupied by the ice sheets. He concluded that the ice had passed through these rifts in the bark. He thought that the water might have been pressed or drawn up through the cambium layer. He wisely dismisses the explanation because it "explained too much since no reason can be assigned why the phenomenon should not be universal and not confined to one species" (7). In the present paper microphotographs of the cross sections of various plants will assign this reason, viz, the difference in the porosity of the stems.

Recent Data.

During the fall and winter of 1913–14 (which may be called an "open" one in that there was no snow until after Dec. 1, 1913) the writer had been walking daily through Rock Creek Park, on his way to and from the United States Bureau of Standards. The route is along the "Beach driveway" which winds along the east bank of the creek. This driveway is bordered by a steep hillside, from 10 to 50 feet in height, which is thinly covered with second-growth trees, the majority of which are oaks and beeches. There is a thin undergrowth of grasses and of various herbaceous plants with annual stems and perennial roots.

From this it may be seen that the habitat of the plant about to be described is different from the one mentioned by Le Conte, which thrives on wet soils. The present observations are on *Cunila mariana* or Dittany, whose stem is an herbaceous annual with perennial roots. This plant seems to thrive on dry ground, even on bare hillsides exposed to the blazing sun, where there is nothing but gravel and a few "asters." Other samples were found under trees where either the shade or the gravelly character of the soil prevented a luxuriant growth of other plants. The finest samples were found on a hillside which contained plenty of moisture and was free from trees, but contained shrubbery.

The first observations were made on a frosty morning in November, 1913. The first example, because of its white ribbony character was passed by, thinking it was something thrown from a passing carriage. The conspicuous white fibrous loops and ribbons drew my attention, and it was at once observed that they occurred upon only one species of herbaceous plant. A sample of the plant was sent to Prof. Cleveland Abbe, of the United States Weather Bureau, who pronounced this a rare and an interesting observation which should be followed up by a more thorough study of the ice formations. While the problem itself seemed a very interesting one in radiation and in the capillary movement of water, it nevertheless seemed an intrusion upon my regular program of radiation work, so that at first but little attention was given to it, other than scattered observations in passing to and from the bureau. As time passed, many diverse opinions were received as to the cause of the ice formation. This called forth additional tests so that the expe-

rimental data now at hand are rather voluminous. In view of the fact that memory is treacherous notes were taken in the field at the time of observation.

Owing to the pressure of other problems requiring close attention, the very first impulse was to dismiss the subject by accepting Le Conte's explanation that the moisture comes from the pith. This explanation was at once disproved, however, by the observations on the splinters of the *Cunila* stem, which formed ice always on the outside of the stem, but never on the pith. This, of course, should be expected for pith is composed of small hexahedral cells along which water can not pass by capillary attraction and it would be very unlikely that it would be transferred by soaking through the cell walls.

Description of the plant.—The stem of *Cunila mariana* is somewhat angular, especially as viewed with the bark on, having a cross section of 1.5 to 2.5 mm. The height of the stalk is from 25 to 30 cm (about 1 foot). The plant stems are very fragile owing to the structure of the stems which contain but little wood fiber. The plant is also weak in structure owing to the great amount of pith and the manner in which the pith is arranged in the stem. As shown in figures 1 and 12 the stem is somewhat rectangular in outline, the pith having a similar shape, but the "corners" are rotated 45°. At these "corners" of the pith there is but little wood between the pith and the bark, and it is along this line that the stem often cracks. Perhaps this is the reason for the persistent belief among the few who are acquainted with the phenomenon that the ice ribbons come from these rifts in the stem. The small stem, weakened by splitting, is an easy prey to the wind.

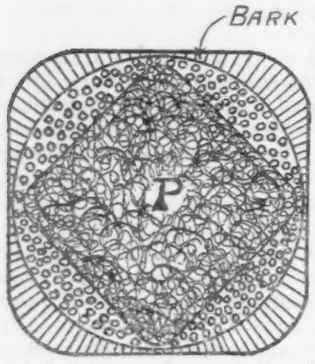

FIG. 1.—Diagrammatic cross section of stem of *Cunila mariana*.

Photographs were taken of thin sections across the stems of heliotrope, thistle, and also of an aster which was found near a *Cunila* stalk. The object of these photomicrographs (which were very kindly prepared by Mr. E. D. Tillyer) is to show a typical example of plants which have but few sap tubes and which form little or no ice fringes; also typical examples of plants which have numerous sap tubes and which form an abundance of ice fringes.

The aster is typical of plants having but few sap tubes. As shown in figure 8 the woody structure is very compact with but few sap tubes. All these microsections are magnified 50 times; thus one can obtain some idea of the great difference in porosity of the different plant.

On only one occasion was ice observed upon the stem of the aster. The ice was a small "tooth" formed close to the ground. From the section shown in figure 8 it is evident that the structure of the wood fiber is so close that the moisture, which is drawn up within the stem by capillary attraction, can reach the surface of the stem at only a very slow rate. Hence the moisture disappears by evaporation as rapidly as it comes to the surface.

The thistle (fig. 9) and the heliotrope (fig. 10) stems have numerous large sap tubes. In the thistle stem there is a row of large tubes situated near the bark. The presence of these large tubes filled with sap may explain the formation of ice fringes as observed by Herschel.

Photomicrographs of thin sections of *Cunila* are shown in figures 11 and 12. The numerous holes in the wood are the "sap tubes" which form an easy path for the moisture to rise within the stem, by capillary attraction. It would be interesting to determine to what extent this capillary movement of water is affected by the temperature of the surroundings.

The explanation of the formation of the ice fringes found to occur so abundantly upon the stems of *Cunila* and which are not found upon other plants, is based upon the presence of a great number of closely adjoining sap tubes within the stem of the *Cunila*. But even the very woody portion of the base of the *Cunila* stem was found to be inactive in the formation of ice fringes.

It was found that the ice fringes rarely start from the side of the stem where the pith is closest to the bark. This eliminates, to some extent, the question whether the pith is instrumental in forming the ice fringes. In the splinters and in the rifted stems of *Cunila*, at no time was ice found to have formed along the line of separation of the stem. This seemed puzzling at first, for it appeared to contradict the idea that the moisture comes from the sap tubes within the stem, in which case one would expect to find the formation of ice fringes facilitated upon the surface laid bare by splitting.

The microsections of the *Cunila* stems show in a very unexpected manner why no ice fringes are formed upon the rifted surface of the stem. As already stated, the rift always occurs at the "corners" of the pith where the woody part of the stem is the thinnest. It may be noticed in figures 11 and 12 that at the four points where the wood is the thinnest there are usually but few, if any, sap tubes. Hence one need not expect to find ice formations upon the surfaces formed by splitting.

Field and laboratory observations.—The field observations were made on isolated plants found scattered throughout the woods; also on three test beds of plant stems without their roots, which were conveniently located along the roadway.

The first test bed "Test No. 1" was "planted" January 7, 1914, with plant stems 10 to 15 cm. long, which had been in the laboratory since November, 1913. This test contained: (1) A stem and branches with bark intact; (2) a similar stem with two coats of shellac varnish; (3) a stem having the bark thoroughly scraped from one side and the other side shellacked over a length of about 8 cm.; (4) a stem scraped on all sides and the one-half of it shellacked; (5) a stem having half its circumference scraped, the other half having the bark intact; and (6) a stalk planted head down. The location proved to be a poor one, the ground not retaining moisture. The place was disturbed, but in spite of this some results were obtained.

Tests No. 2 and No. 3 were "planted" on January 11, 1914, and consisted of about two dozen plant tops and stems which had been broken off by the wind. They were placed on a gravelly bank which was not desiccated by the wind and sun. Some of these stalks were covered with soil up to their branches. In none of the field tests were the tops of the stalks covered to prevent deposition of atmospheric moisture. Test No. 2 contained several stalks of heliotrope and stems of wild grapevine, which, of course, at this late date were entirely dead. As already mentioned, Herschel found ice fringes on the green stumps of heliotrope. At no time did ice fringes form on the heliotrope (nor on the wild grape stems which were green). Special note of this fact was made on January 22 and February 2, 1914.

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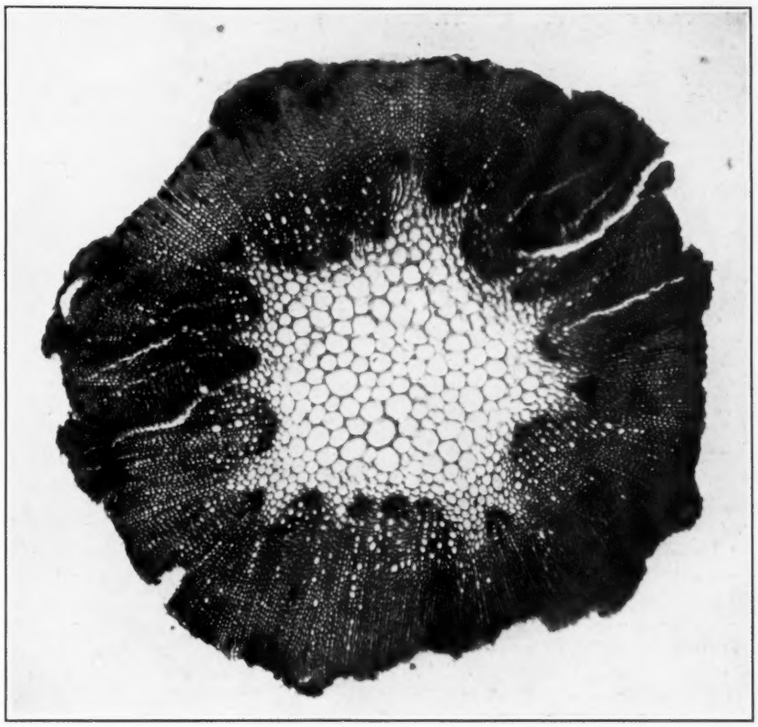

FIG. 8.—Cross section of stem of aster, showing compact woody structure and few sap tubes. Magnification 50.

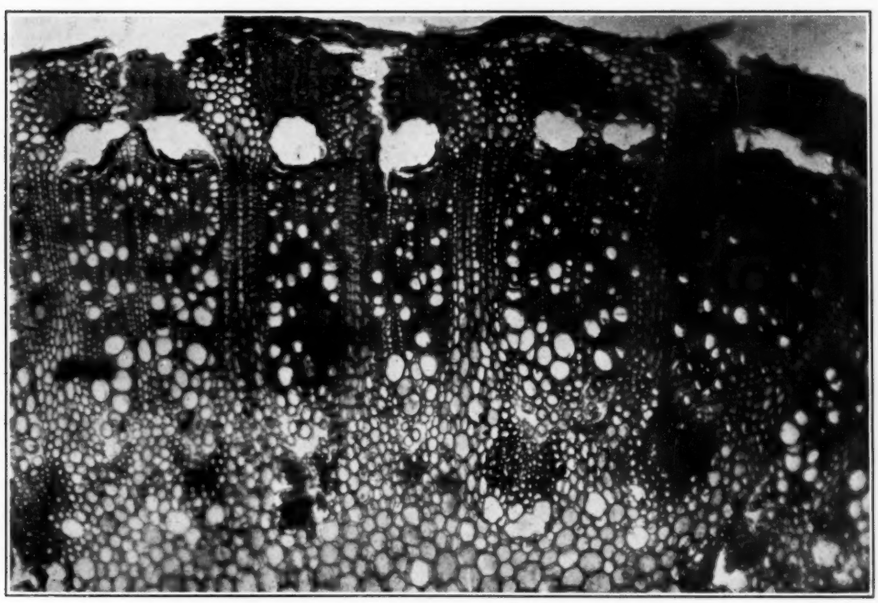

FIG. 9.—Portion of a cross section of stem of thistle, showing numerous large sap tubes. Magnification 50.

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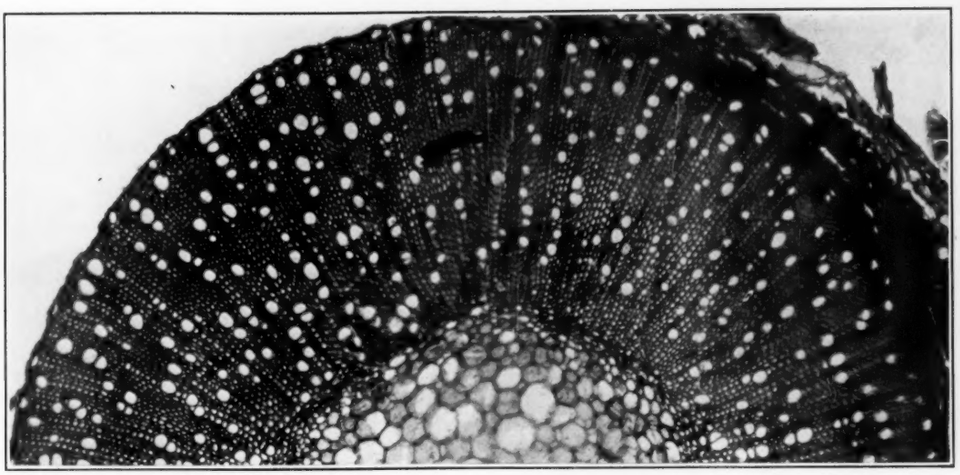

FIG. 10.—Portion of a cross section of stem of heliotrope, showing numerous sap tubes. Magnification 50.

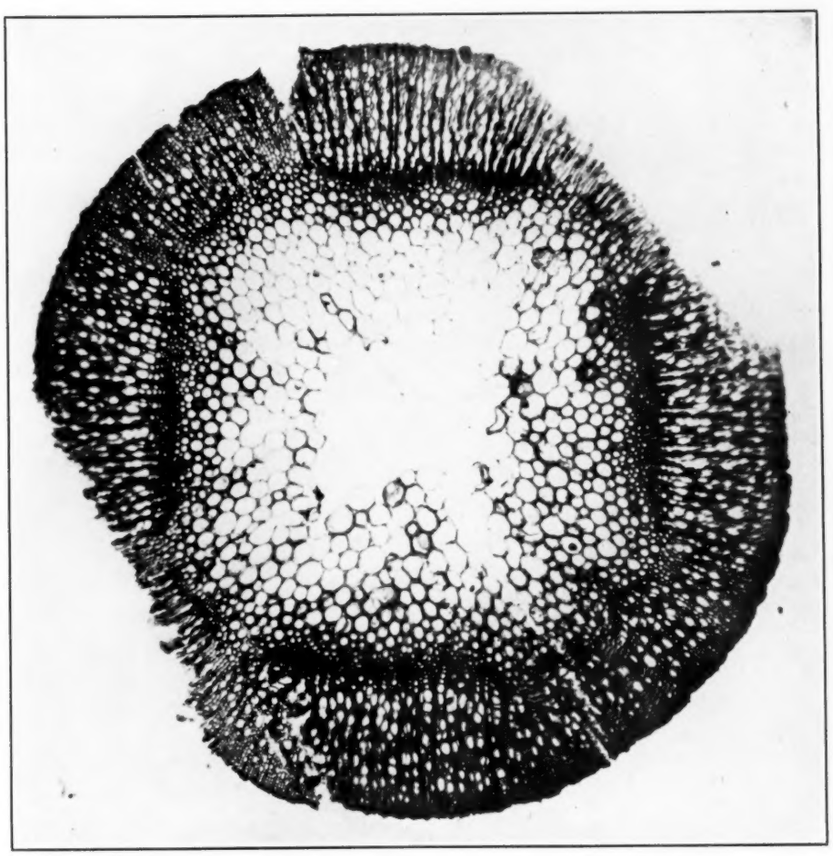

FIG. 11.—Cross section of stem of *Cunila mariana cunila*. Magnification 50.

The laboratory tests started on January 30 and were made on plant stems placed in a receptacle containing water. In the first and second laboratory tests, A and B, the samples were mounted in a small porcelain crucible, as shown in figure 2. The plant stems were fastened into a piece of heavy cardboard by means of Khotinsky cement. The cardboard was then covered with paraffin on both sides and sealed with paraffin to the top of the crucible. A small pinhole equalized the air pressure, thus preventing any possible hydrostatic pressure. The protruding stems were covered with a glass beaker, which prevented deposition of moisture from the air.

Two additional laboratory tests were made on plant stems placed, in test C, in a test tube, as shown in the photograph, figure 19; and D, in a wide-mouthed bottle. In all these laboratory tests the stems were covered to prevent deposition of atmospheric moisture.

Experiments showing how the water is conveyed.—The field observations, "Test No. 1," showed that the water is not transferred along the cambium layer or the bark. Ice was formed on that half of the stem which was scraped, but none was formed upon the part (whether scraped or unscraped), which was covered with shellac. This observation was confirmed on different occasions, special note of this fact having been made (test 1, specimens 3 and 4) on January 8, 12, and 27, and February 2 and 3. In specimen No. 2 of this test the ice forced out the shellac at the juncture of two branches on February 3. On these dates (as well as others which it would be too tedious to record in this paper) my notes show that ice fringes, large and small, were formed upon numerous plants contained in the plats described as tests 1, 2, and 3.

The laboratory tests A and B showed that starting with stems that had been drying for nine weeks in the laboratory the moisture is transferred very rapidly after placing the stems in water. In test A (see fig. 2) four scraped samples were thoroughly covered with an impervious cement at the point of contact with the cardboard *C*. About 2.5 cm. of the stems extended above the support. The next morning (Jan. 30) two samples were found thoroughly soaked. They were from the upper part of the plant, hence thin-walled and less "woody." The third sample, which was taken from near the root, was inactive. The fourth showed slight moisture at the top and by night (24 hours in all) this sample was thoroughly soaked.

The second laboratory test, B, consisted of the two most active samples of test A thoroughly dried and covered with cement, *K*, as shown in figure 2, and placed in water containing a red dye. The sample *a* was covered at the top, *K*, so that the water would have to come out at the sides. The sides of the immersed part of this stem were covered with cement, so that the water would have to traverse the sap tubes in order to reach the top. The immersed end of sample *b* was covered with cement, so that the water would have to soak in through the sides in order to traverse the stem.

The next morning, February 3, 1914 (uncolored), moisture was observed on the sides of *a*, and the top of *b* showed the red dye. Evidently the water had traversed the stems to a height of about 3 cm. by capillary movement. In the subsequent tests, C and D, the stems were more than 6 cm. in length, and it was found that the water rose to a height of 5 cm. However, when uncovered and exposed to the wind the moisture did not rise higher than 1 cm. to 2 cm.

Further tests showing that the water comes from within the stems.—There are several observations which indicate that the water required for the formation of ice fringes comes from within the stem, and that the fringes are not caused by accretion or sublimation as in hoarfrost. One of the observations applicable to this question was made in connection with the laboratory tests, C and D, discussed elsewhere in this paper. The morning following the formation of the ice fringes on the *Cunila* stems it was observed that considerable water had disappeared from the glass receptacles. The glass beakers covering the stems were perfectly clear, showing that no water vapor had condensed (and frozen) upon them. Evidently the ice

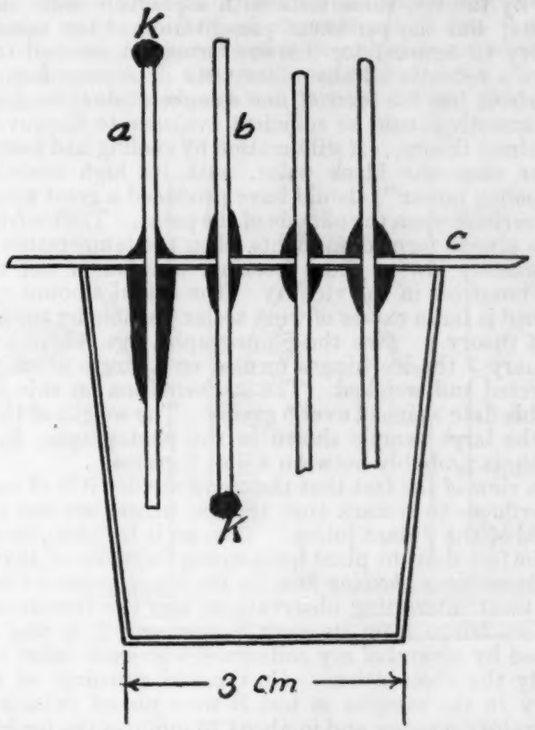

FIG. 2.—Arrangement of plant stems in laboratory tests A and B. *K* sealing of Khotinsky cement, *C* paraffin-coated cardboard.

fringes had been formed from the water that had disappeared from the glass receptacles.

Another observation (January 6) was on a plant in the woods, surrounded with green moss and well covered with leaves of trees. The stem had several large ice fringes that were hidden by leaves. The leaves were covered with hoarfrost.

A very convincing field test was made by painting the stems with asphaltum in turpentine. If the ice formations were the result of condensation of moisture by rapid cooling, then the black paint should have ice formed upon it. In the afternoon of January 13 (the ice fringes having melted as usual) a number of *Cunila* plants free from bark, situated in various parts of Rock Creek Park, were given a coating of asphaltum paint. Test No. 2, mentioned above, contained several painted stems. As shown in the photographs, figures 15–18, the outer edge of the ice fringe is smooth, which could hardly be the case if the formation were similar to that of hoarfrost. On January 27 it was found that on two plants in test 2 ice fringes had pushed out the asphaltum varnish which was found adhering to the outer edge of the ice, 1.5 to 2 cm. from the stem of the plant.

In test 4 the ice had pushed out the asphaltum and had formed a fringe in the rent in the paint. For some days

subsequent to this date there was no freezing weather, but on February 3 other stalks were found in which the asphaltum varnish was pushed out and adhering on the outer edge of the ice fringe. It may be added that for some days after applying the asphaltum paint, the formation of ice fringes seemed to be inhibited.

The field tests (test 1) described above, page 492, in which one side of the stem was covered with shellac varnish, showed that the moisture was not conveyed from the ground upward along the outside of the stem.

In view of the fact that the bark is often found pushed out by the ice, these tests with asphaltum seem superfluous; but the persistent presentation of the hoarfrost theory to account for this ice formation, seemed to require a reductio ad absurdum test. The mere fact that hoarfrost has the form of fine spiculæ while these fringes are smooth should be sufficient evidence to disprove the hoarfrost theory. If sublimation by cooling had been the cause then the black paint, with its high emissivity ("cooling power") should have produced a great amount of hoarfrost upon the outside of the paint. The ice fringes were always formed on nights when the temperature was sufficiently low to cause freezing, whether or not there was hoarfrost in the vicinity. The actual amount of ice formed is far in excess of what seems possible by the hoarfrost theory. (See the photographs, figs. 13–19.) On January 7 the ice fringes formed on a single plant were collected and weighed. The ice formation on this plant on this date weighed over 5 grams. The weight of the ice on the large sample shown in the photographs, figures 15–19, is probably between 4 and 5 grams.

In view of the fact that the stems are dry it is of course superfluous to remark that the ice fringes are not composed of the "plant juices." The ice is tasteless, in spite of the fact that the plant has a strong fragrance of thymol.

Observations showing how the ice fringe grows.—One of the most interesting observations was the formation of the ice fringe from its very beginning. This was witnessed by several of my colleagues, who were called in to verify the observations. On the cold morning[1] of February 16 the samples in test B were placed outside the laboratory window and in about 20 minutes the ice fringe was observed to be forming. It consisted of a row of fine hairs extending up and down a length of about 4 mm. of the stem and projecting horizontally 0.2 to 0.3 mm. (See fig. 3, *A*.) These filaments were visible only when viewed against skylight, and they melted immediately on lifting the glass cover. The fringe did not appear to form at the line where the pith is closest to the surface of the stem (see fig. 1). This experiment was repeated again during the evening. Within half an hour after placing the samples (test B with additional samples) in the cold air one stem showed several fringes in the form of thin transparent "teeth," each one being about 12 mm. in length and about 1 mm. in height. Another stem showed a fine hairy fringe which was visible when viewed against a gaslight. Within half an hour this hairy fringe appeared to be solid, with some of the fine hairs extending horizontally outward through the solid "tooth" of ice, as shown in figure 3 *B*. This, of course, is the general structure of the fringes. By the next morning numerous wide fringes had formed on these stems. In another sample the tooth of ice pushed out a narrow strip of bark similar to the illustration given in figure 3 *B*. In these tests the receptacle containing the water was small, hence the whole cooled very rapidly and the water froze, thereby preventing the growth of the ice fringes. It is to be noticed that the ice fringe forms some distance up the stem, at a point where it cools the quickest and where the moisture has risen to about its maximum height.

Test C started February 17, embraced half a dozen samples of *Cunila* and a stem of an "aster" in a large test tube. The test tube was embedded in wool to retard

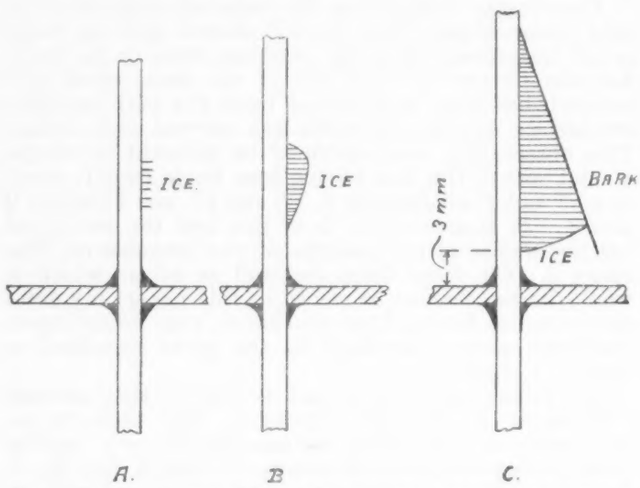

FIG. 3.—Stages in the growth of the ice fringe under the experimental conditions of figure 1.

cooling and freezing. Within 15 minutes after placing this arrangement outside the laboratory window, two small fringes 1.5 mm. long and about 0.3 mm. high were noticed when viewed against the skylight. This test was prolonged for some days and nights. On February 18 it was photographed (see fig. 19) to show that ice fringes form as readily when the stems are in water as when they are attached to the roots. In this photograph, which is magnified slightly, about one-third of the upper part of the largest fringe is broken off. These fringes appear a little more transparent than usual, owing to melting while taking the photograph.

No ice or moisture was formed on the aster stem. This agrees with the field observations, which furnisb only one instance where there was an ice fringe found upon an aster stem. In this field sample of aster there was but little ice, which was very close to the ground. In test C all the *Cunila* stems showed moisture, and ice was formed on nearly all of them. The thinnest stems formed the most ice.

Test D, started February 17, consisted of an assortment of 10 *Cunila* stems mounted in a large, wide-mouthed bottle having a capacity of about 1 liter. This bottle, wrapped in hair felt, was placed in a box kept ou side the laboratory window. The stems were supported as usual by the cardboard lid, which was thoroughly covered with paraffin. The protruding stems were covered as usual with a large glass beaker, which rested closely upon the felt.

[1] The thermograph (altit. 62 feet above street) at the Weather Bureau recorded the following temperatures during the forenoon of *Feb. 16, 1914:*

At 1ª	2	3	4	5	6ª	7	8	9	10	11ª	12 M.
°F. 22	°F. 22	°F. 21	°F. 21	°F. 23	°F. 24	°F. 24	°F. 24	°F. 24	°F. 26	°F. 25	°F. 24

Snowing, 2.30ª–5.25ª; 7.25ª–8.10ª.
Maximum = 26°, 9–10ª.
Minimum = 19°, from 8–12 p.

As may be seen from figures 1, 11, and 12 the *Cunila* stem on drying (shrinking) splits easily into four parts, owing to the small amount of wood fiber at the four sides of the stem. One of the samples used in test D was a splinter, consisting of one-quarter of the stem, about 6 cm. in length, with a line of pith adhering to the inner side. On the following morning, and on subsequent days, this splinter showed a fringe of ice on the woody surface, but at no time was there ice formed on the pith. One sample consisted of one-half of the stem as shown in figure 4 *A*, and on February 20 a solid fringe or "tooth" of ice was found projecting out to a distance of 3½ mm. It was about 2 mm. wide at the base and extended perhaps 1 cm. along the stem. An interesting feature (which to the writer became a common observation) was that the ice fringe did not always start at the "corner" of the stem where the wood is the thickest; neither did it start at that part of the stem where the wood is thinnest, but at a mid-point as shown in figure 4 *A*. From the photomicrograph of a thin section of the stem it appears that the largest part of the ice fringe may form at the point where the sap cubes lie nearest the surface, hence where the moisture can be most easily supplied.

in figure 3*C*. This seems to be the usual manner in which the stems are stripped of bark. The bareness of the stem, however, does not seriously affect the ice formation, as may be noticed in the accompanying photographs. One sample had a fringe 3.5 cm. in length and 2 to 3 mm. thick at the base. When the bark is still intact, the ice formation appears to occur most frequently at the "corners" of the stem. (See fig. 1.) In the bare stems the ice was sometimes found (test D, Feb. 17) to be formed well around the stem as shown in figure 4*B*, and numerous field observations showed that this is the result of the fusion of two fringes, leaving a wedge-shaped free space between them. The commonest form is shown in figure 4*G* (field observations of Jan. 6 and 8), in which the ice ribbons were described as a composite of thin sheets which were estimated to be 0.3 mm. in thickness. The open space was perhaps 3 mm. wide at the base. The base appeared to be a solid shell 0.5 mm. in thickness. One could easily look through this wedge-shaped opening. Sometimes these fringes adhere well to the stem so that the ribbon breaks across the open space. After sunrise the stem warms rapidly, which no doubt explains the ease with which the ice ribbon is usually separated from the stem.

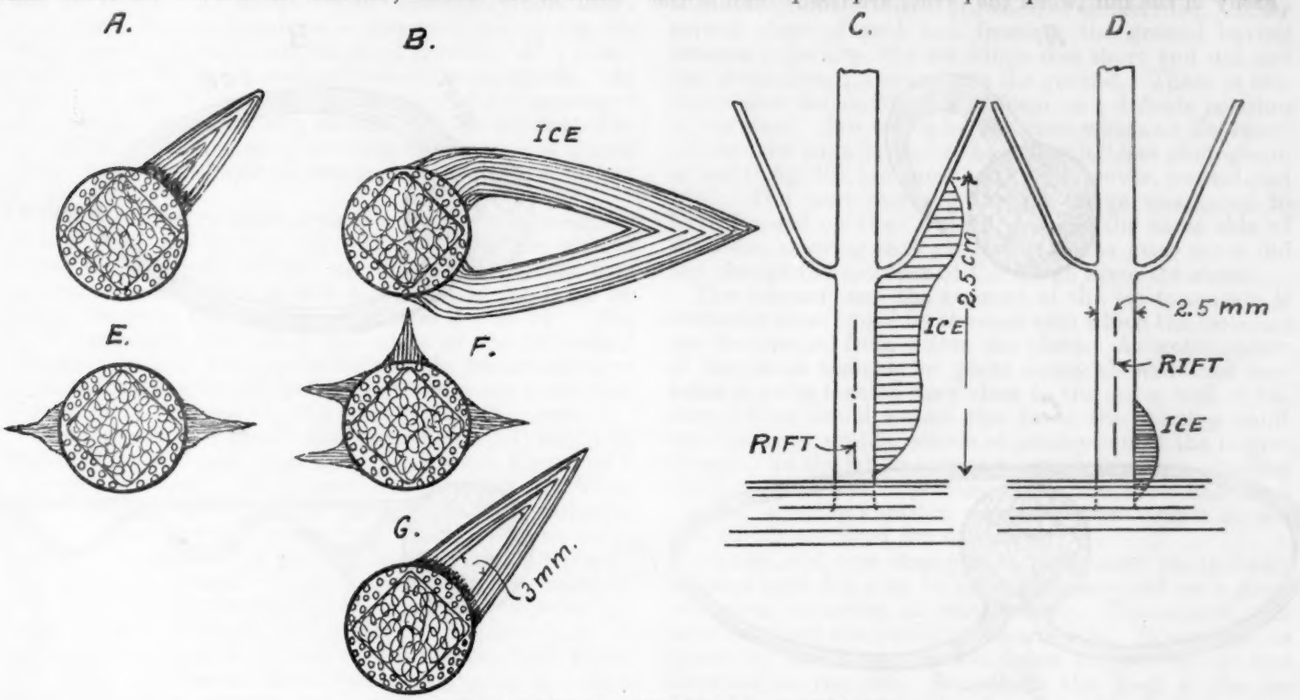

FIG. 4.—Forms and positions assumed by the ice fringes on *Cunila* stems.

Another sample in test D consisted of a thin stem (1.5 mm. cross section) which was split into four segments for a length of about 2 cm. The ends of the stem were intact. My notes, recorded on the morning of February 20, state:

> One can see through the cracks in the stem. Two ice fringes are formed, extending outward to a height of 7 mm. and extending 12 mm. vertically along the axis of the stem; but *they are not formed in the cracks.*

In fact, the point of attachment of the fringe to the stem, as examined under a reading glass, did not even extend close to the cracks.

In some of the samples in test D the stems were entirely free from bark (see the photograph of test C) while some were covered with bark. In the latter samples the ice pushed out a narrow strip of bark 1 mm. wide, as shown

The bare stems used in this test were old stalks from which the bark had been separated by previous ice formations in the woods. Evidently the laboratory test did not interfere with the ice formation. The roots are not necessary for the production of the ice fringes. As a matter of fact the stalk and the near-by roots are dead, although the rest of the plant (new growth) is perennial.

The ice usually formed on the flat side of the stem, but, as already mentioned, it often was found to cover the whole side, as shown in figure 4*B*. In some stalks the ice "tooth" was found (note of Feb. 17) to have formed near the "corner" of the stem, as shown in figure 4*A*. Other ice "teeth" were observed in process of formation, as shown in figures 4*E* and *F*, the ice being solid, about

3 mm. in length and half a millimeter in height. Figure 4*E* is observed on test B, February 13, and figure 4*F* was found in the field on January 11, 1914. Since it is generally believed that the stems are split by the frost, it is important to notice that in these laboratory tests none of the stems were rifted by the ice formation. The rifted stems used in these tests were samples which had cracked on drying and shrinking, after having been in the laboratory.

The ease with which these stems became saturated with water after having been drying for weeks is another item worth noticing. All the stems used in tests C and D had been in the laboratory for some time. Some of them had been gathered in November, 1913, and had been freed of bark by previous ice formations.

It is generally supposed that the ice is formed more easily in the fall (when the plants are fresh) than in the late winter. This seems to be true, to some extent, according to my field observations and my laboratory tests. In tests A and B the ice did not seem to form so abundantly after the stems had soaked for some weeks, as though the sap tubes became clogged or the plant had begun to decay.

Although the laboratory tests were continued after February 21, no records were kept, and at the risk of being prolix the notes of the last two mornings, February 20 and 21, are given herewith.

On February 20 (warm and rainy the first part of the night, cold and freezing in the morning) moisture and ice fringes were found extending 2.5 to 3 cm. up the stems. Test C contained 5 *Cunila* stems and one "aster" stem, ice fringes were found on 4 of the 5 *Cunila* stems, but no ice or moisture was found on the aster stem. There were 2 to 4 fringes on each stem, some of the fringes being 1 cm. wide, i. e., extending outward horizontally 1 cm. from the stem. The last laboratory observations were made on the morning of February 21, 1914. Tests B, C, and D were under observation, having, of course, been started the previous evening. Test D had ice fringes on 7 of the 9 stems of *Cunila*. The thick *Cunila* stumps did not seem to be able to form ice; and there was no moisture on the outside. Test C had ice fringes on all the 4 *Cunila* stems, but no ice or moisture was on the aster stem. The aster is one of the common plants found growing near some *Cunila* stalks, but was so badly broken that it was not identifiable with any of the numerous asters which abound in the locality. Some stems had 4 fringes, but no ice was observed in the cracks which were in one of the stems. Some of the fringes were curled back against the stem.

Test B showed ice fringes on two of the three stems under observation. The third stem was a very thick one, which showed a fine line of ice just starting. The fringes were small, being only about 3 mm. long and 2 to 3 mm. high.

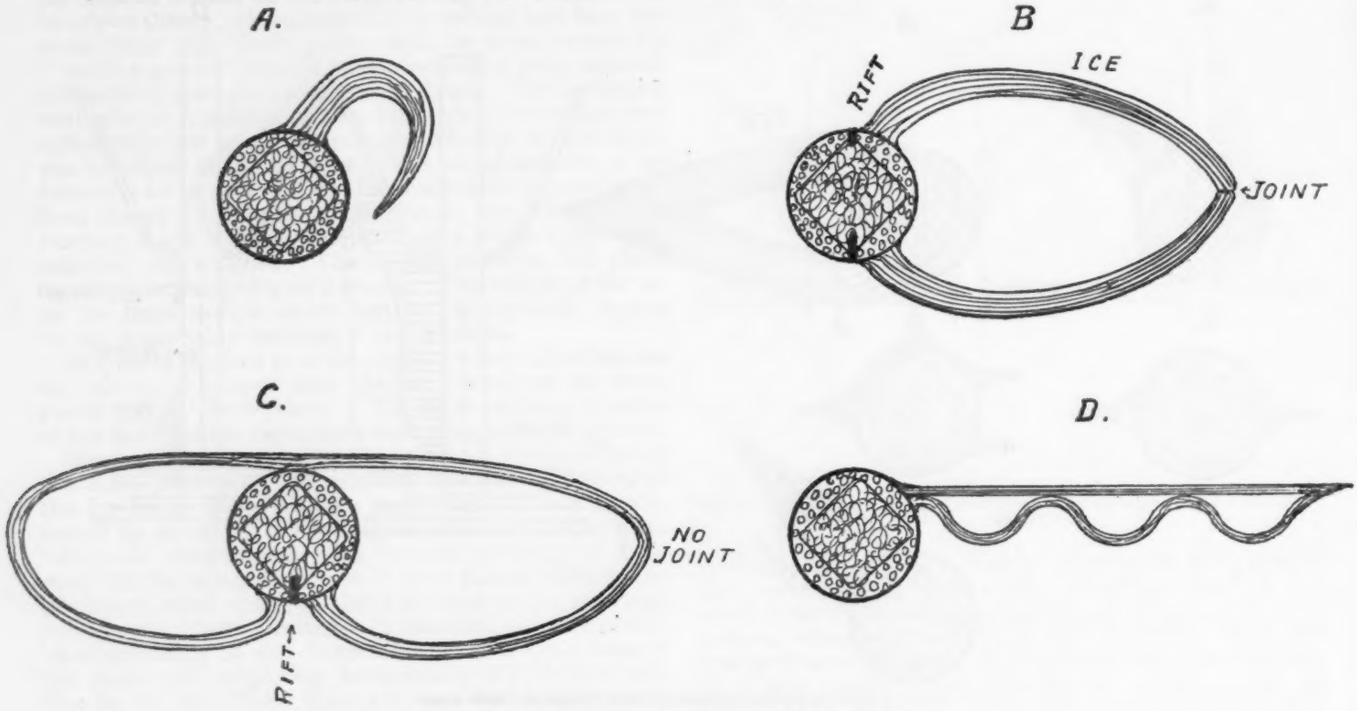

FIG. 5.—Forms and positions assumed by the ice fringes on *Cunila* stems.

The peculiarity of the fringes on February 21 was that in all three tests (B, C, and D) the fringes were small and the outer edges were curved back against the stem, as shown in figure 5*A*. This seems an interesting observation for it serves to explain the peculiar ice loops so frequently observed in the field. They no doubt start as a thin fringe (as in the laboratory test of February 21), one side of which grows faster than the other, thus forming a curved fringe (see fig. 5*A*), which in some cases seems to freeze against the stem. As more ice is formed the loop is merely enlarged, as in figure 5*B*, which is a field observation (Jan. 18, 1914) on a rifted stem where no ice was formed in the rifts. This loop was jointed at the ends. A still more remarkable formation (observed Jan. 18, 1914) is shown in figure 5*C*, which also showed no ice formed in the rift. In this sample it was especially noted that the loop was not jointed. A further illustration of the composite character of the fringe is shown in figure 5*D* (field observation Jan. 18), in which one side of the fringe has intermittently grown faster than the other side, thus forming a wavy, fluted surface, while the

other side is smooth. My notes of January 18 state that the loop is usually jointed at the outer edge (fig. 5*B*), the fringe usually starting near the rift.

These illustrations seem to indicate that the ice fringe begins as a row or several rows of fine, hair-like, filaments of ice, as shown in figure 3*A*. These filaments of ice, which remind one of the finest filaments of mold, increase in number, fill in the gaps, and form a continuous film of ice. They extend upward and downward along the axis of the stem, and they widen out, thus producing the sharp, wedge-shaped formation of ice which one finds in the early stages of ice-fringe growth. It is possible that when the plant is exposed in the open fields, the fine, hair-like filaments which constitute the first stage of the ice fringe are not formed and that the thin solid, tooth-like formation constitutes the beginning of the ice fringe. As shown by the laboratory test, however (test B mentioned on a previous page), the ice fringe passed through both stages of growth. At 7 p. m., February 16, the fine hair-like filaments were visible. At 7:30 p. m. these filaments had multiplied and coalesced into a solid film with hairy streaks in it, as illustrated in figure 3*B*. The following morning the fringe had grown larger than the sample shown in the photograph of test C (fig. 19).

These laboratory tests serve to explain the filamentous structure of the mature ice fringes. They are always found to be fibrous and the ice ribbon often breaks into several ribbons. This is well illustrated in the large ice fringe shown in the photograph of test C (fig. 14). The light horizontal lines show the edges of the individual fringes. In fact this particular sample contained large open spaces, in spite of the fact that it was not more than 2 mm. in thickness, i. e., the thickness of the stem.

The formation of the ice filaments (figure 3*A*) might be regarded as evidence supporting Le Conte's theory of a "projectile force" which produces the fringe. Then arises the difficulty of finding the cause of the "projectile force." The physical forces now familiar to us seem sufficient to account for the phenomenon without invoking unknown forces. These known physical activities are: (1) Cooling by radiation; (2) a rapid capillary movement of water through the interior of the plant; and (3) sufficient moisture in the soil, so that the capillary forces can bring moisture to the surface at a greater rate than that at which moisture passes into the air by convection and by evaporation. The capillary movement of water may possibly be accelerated by the temperature gradient in the stem, which is cooler on the outside.

The main difficulty in this explanation of the cause of ice fringes lies in the fact that the second stage in their formation is an apparently solid wedge of ice (see, however, fig. 3*B*), whereas the mature fringe is fibrous in structure, very friable, and often separates into a series of wide ribbons as thin as tissue paper. This fibrous structure, however, may be the result of reformation by variations in air temperature, by evaporation, etc., which produces the white fringe shown in the photographs. The laboratory formations never appeared quite so white. The great transparency of the sample, test C, shown in figure 19, is owing to melting while taking the photograph. The field specimens differ greatly in translucency. On a cold frosty cloudy morning (Jan. 18?), the atmosphere having a "damp" feeling, the numerous ice ribbons, 2 to 3 cm. in length, were conspicuous for their great transparency.

What determines the location of the ice fringe upon the stem?—The ice fringe is usually found to adhere loosely to the stem. It seems to continue to increase in size even when the ground surrounding the plant is frozen to a depth of 1 to 2 cm. As Le Conte found, the ice formation ceases its growth after the ground has become frozen to a considerable depth. The moisture in the stem is then found to be frozen, and ice is found in the (rifted) stems. On very cold mornings the ice fringe extended down to the ground (observation of Jan. 11). How close the fringe approaches the base of the stem depends, of course, upon the temperature of the ground. The height to which the fringe can form seems to be governed by the rate of capillary movement of the water, and the rate of evaporation (and convection) from the surface. In my laboratory tests where the plants were covered and protected from the wind, the moisture rose 5 to 6 cm. in the stem; but on removing the cover evaporation reduced this height to 1 to 2 cm. When the soil was wet the ice ribbons were the widest. For example, on January 7, a width of about 4 cm. (1½ inches) was recorded. After several days of cold and freezing, the ground having become quite dry, the ice fringe was short and did not rise more than 1.5 cm. above the ground. There is evidence that the ice fringe may form on a definite position of the stem. For example, one stem which on February 17 formed a large fringe on the "outside" (see photograph of test C, fig. 19), i. e., near to the glass cover, was rotated 180°. The next morning the ice fringe was found to have formed on the "inside," i. e., on the same side of the stem, showing that proximity to the glass cover did not change the location of the fringe upon the stem.

The location and the amount of the ice formation is evidently determined by the ease with which the moisture can be supplied from within the plant. An examination of the cross sections of plant stems showed that sap-tubes may be located very close to the outer wall of the stem. One would expect this to be the starting point and the most prolific source of production of the largest fringes. In the laboratory test sample the stem showing this property was one from which the bark had been scraped, and the abrasion may have been deeper on the side which produced the most ice.

In the field one strong, weather-beaten plant (stem without bark 2.5 mm. in diameter), situated on a steep bank was observed all winter long. Throughout this time it formed the ice fringe on one side. It was split as shown by the dotted lines in figure 4*C*, but no ice was observed in the rift. Sometimes the base of the ice "tooth" was almost solid and embraced half of the stem, as shown in figure 4*B*. After a rain when the ground was quite wet, the ice fringe extended 2 to 2.5 cm. up the stem and out along a branch (observation of Jan. 11), as shown in figure 4*C*. On other mornings when the ground was dry and powdery, there was but little ice formed above the loose earth which continued sliding down the steep bare hillside. The ice fringe, however, whether a wide ribbon or a short wedge-shaped "tooth" (fig. 4*D*), half buried in the dry shifting soil, was always formed on the same side of the stem. The clump of 3 or 4 plants, of which this was one stem, never formed such long ribbons as were to be observed on other stems situated on a lower level on this same bank, where the ground was always moist. The plants of test 2, described elsewhere, were located on the lower level of this steep hill; also stumps of *Cunila*, from which the tops had been cut. No ice was observed to form on the cross section of the stump; but long curled ribbons of ice continued to form along that side of the stem that was at the level of the ground. The soil itself formed excellent samples of ground ice.[2] It was therefore an interesting sight to

[2] The term "ground ice" here used by the author must be assumed to refer to ice columns properly so called.—EDITOR.

sometimes observe the ice fringes from the stumps of *Cunila* protruding out over the ground ice. The ground ice formed only after rain when the ground was wet, i. e., contained a certain amount of moisture.

Description of photographs of ice fringes.

The attempts at photographing the ice fringes as they occurred in the woods were far from satisfactory. This was owing to the fact that at 8 a. m. the illumination was weak. A wide stop was used in the camera, and consequently the objects are in focus only in the center of the photograph. They serve the purpose, however, to illustrate their general appearance as found in the woods. The ice fringes are viewed at an angle of almost 45°. However, a general idea of the size of the fringes may be obtained by comparing them with the accompanying pocketknife, which is about 14 cm. in length.

The photograph forming figure 13 was obtained on January 7, 1914. It is typical of what one finds as regards size and general appearance of the ice fringes. The fringe in the lower left-hand corner is composed of three whorls; the open space in the fringe nearest the knife is shown by the round dark spot in the center. The brightest ice fringe in the stalk in the center of the picture is not unlike the large sample shown in figures 15 and 16. This photograph shows seven stalks with ice fringes. One formation in the lower right-hand corner of the photograph is broken. The *Cunila* stalk upon which this fringe was formed (the stalk with the three branches) shows the bark pushed out at the base of the stem, with some ice still adhering to it.

Figure 14 was obtained in the middle of January. The ice formation in the center of the photograph contains four beautifully folded fringes whose markings are unfortunately lost in the print.

The finest photographs (figs. 15, 16, 17, and 18) were obtained by collecting a number of ice fringes one cold frosty morning (Jan. 6, 1914) and having them photographed at the Bureau of Standards. Grateful acknowledgment is due Mr. E. D. Tillyer for his painstaking care in making these photographs, which no doubt are the finest records yet obtained of these beautiful ice formations.

In figure 15 the four most conspicuous ice fringes are lettered *a*, *b*, *c*, *d*, which makes identification easy in figures 16, 17, and 18. In these plates the ice fringes were photographed from different sides. In figure 15*a* it may be noticed that the stem is free from bark.

In figure 16*a* an extremely thin delicate fringe may be noticed protruding from what appears to be a rift in the stem, but what in reality is a piece of bark. It is an excellent illustration of the second stage in the formation of the ice fringe as described on page 494 and illustrated in figure 3*B*. Figures 17 and 18*a* give further views of this ice formation. It consists of two large fringes, twisted and whorled. Figure 17*a* shows to advantage the oft-mentioned, thin, wedge-shaped fringe (see fig. 16*e* and *f*), protruding (upward in the photograph) from above the large fringes. The *Cunila* stalk *a*, shown in these photographs, is typical of what one finds after several ice formations when the stem is well stripped of bark. The stem is 2.2 mm. in diameter and it is not rifted. As shown in figure 17*a*, the "width" of the fringe adhering to the stem is 3 cm. It extends out horizontally 3 cm. from the stem. The distance from the stem to the extreme distal end of the loop is 4 cm.

Figure 15*b* consists of three splinters united at the base of the stem. They are, of course, the remnants of the stalk, which had long since disappeared. The dark line in the wood is the pith, which is shown to better advantage in figure 18*b* and figure 6. Figures 16 and 17 show the pith side of another splinter. We thus have a photographic record of the ice formation upon both the unrifted stalk and the rifted stalk (figs. 15, 16, 17, and 18*c*) and upon the bare splinters. This is an unusually interesting ice formation. The peculiar whorl in the center (figs. 16 and 17*b* are top views) is the meeting point of two fringes (see fig. 6), both of which began curving clockwise. The extreme thinness and the great transparency is to be noticed (see also fig. 3*d*) by the light and the dark streaks through the fringes.

The small ice fringes on the stalk shown in figures 15, 16, 17, and 18*c* are of interest because they occur upon a thin stem which is split into two parts, the rift being easily distinguished in the photographs. In fact, most of the rift is above the ice fringes. This ice formation is also conspicuous in having pushed out some of the bark as illustrated in figure 15*c*. This is an excellent photographic record showing that the ice is not formed upon the pith (fig. 15*b*) or in the rift of the *Cunila* stem.

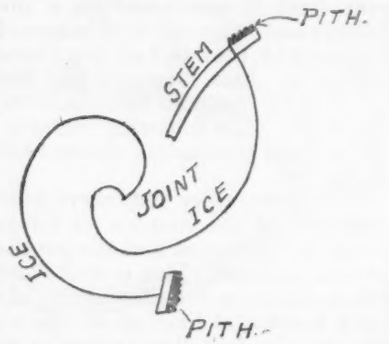

FIG. 6.—Diagram illustrating the structure of a whorl due to the meeting of two fringes such as shown at *b* in the photographs, figures 16 and 17.

Figures 15, 16, 17, and 18*d* give a further illustration of the formation of ice fringes upon fragments of stems of the *Cunila*. The sample is a very small one. The stump of the stalk had to be cut out of the ground in order to obtain the fringes. Some of the soil is still adhering to the stem. One of the fringes is broken off. The extremely thin translucent fringe (it appears to be dark owing to the dark background) on the right hand side of figures 15 and 18*d* is an excellent photographic record of the manner of growth of the ice fringe as described on a previous page. The growth of the fringe is along a straight edge, which appears almost horizontal in the photograph. This, however, is partly owing to the peculiar curvature of the fringe. The distal edge is straight and smooth just as it started when near the stem. The photographic record is, therefore, an excellent contradiction of the hoarfrost theory of accumulation. In the tests with the asphaltum (p. 493) the ice fringe had a similarly formed straight edge. The dark streak along the fragment of stem is pith. The ice fringe is upon the woody side of the stem.

Figure 18 (omitted) shows the upper parts of the stem, a few leaves, and the showy seed capsules. All the photographs show fragments of ice fringes with bright and dark streaks due to the difference in thickness and bend in transparency of the ice.

Figure 19 is a photographic record of laboratory test C. It was taken by the writer February 18, 1914. The test tube was about 20 mm. in diameter, which gives one some idea of the dimensions. The test is described on page 494. This record is of interest mainly in showing that the *Cunila* stems, after having been in the laboratory for some months, form ice fringes just as they do when attached to the roots.

To face p. 498.

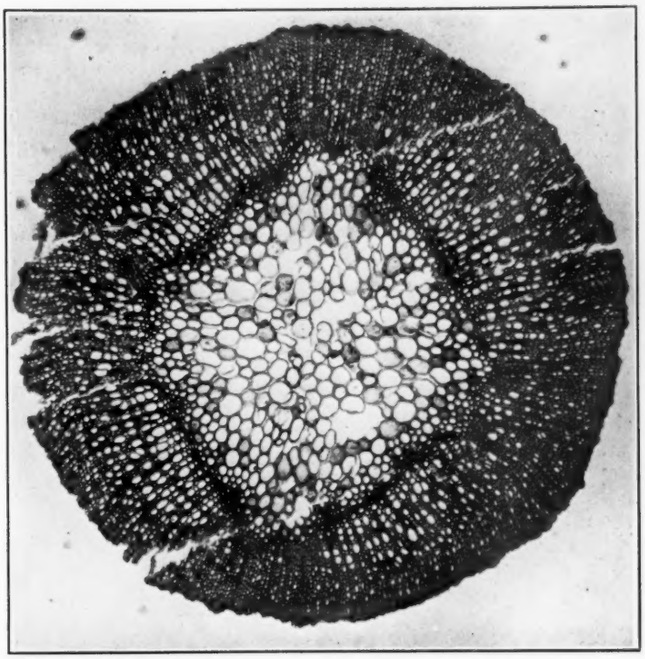

FIG. 12.—Cross section of stem of *Cunila mariana*. Magnification 50.

FIG. 13.—Photograph of a typical field appearance of ice fringes, taken January 7, 1914, looking down at an angle of about 45°.

FIG. 14.—Photograph of four beautifully folded fringes, January, 1914.

FIG. 15.—Details of ice fringes collected January 6, 1914. *a*, *b*, *c*, and *d* are identical in figures 15, 16, 17, and 18. (Photograph by E. D. Tillyer, U. S. Bureau of Standards.)

FIG. 16.—Further details of the views in figure 15.

To face p. 499.

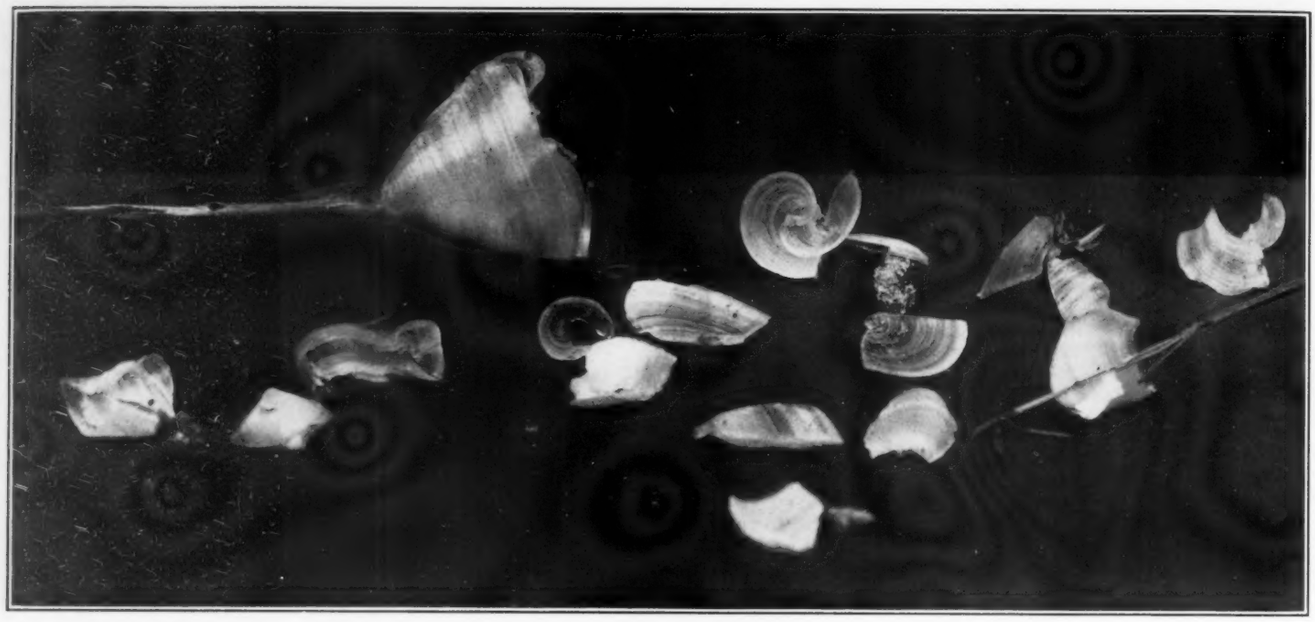

FIG. 17.—Enlarged view of the details of figure 15.

FIG. 18.—Results of laboratory test C, taken on February 18, 1914. Test tube about 20 mm. diameter.

Ice formation in a large body of water.—In view of the possibility that the ice formed at the bottom of a river (the anchor ice proper, as mentioned at the beginning of this paper) may be owing in part to some other cause in addition to the high emissivity of the river bottom, it is desirable to call attention to the following peculiar formation of ice as the result of cooling and refrigeration in a body of still water.

In test D, already described, the receptacle containing the water was a wide-mouth bottle, 6 cm. in diameter at the top, and about 14 cm. in height. The bottle was wrapped in hair felt and tightly packed in a box. Cooling was therefore mainly by conduction and radiation from the top. On one occasion it was observed that instead of the ice freezing solid across the top, there were several extremely thin "curtains" of ice suspended in the water as shown in figure 7. They were visible only in intense sunlight. Several thin, narrow, saw-toothed blades extended far down inside the bottle. They seemed to take the line along which refrigeration occurred as a result of cooling, principally by conduction and radiation at the top of the vessel. It would be desirable to determine whether the density of these fine ice spicules is the same as that of a large mass of ice.

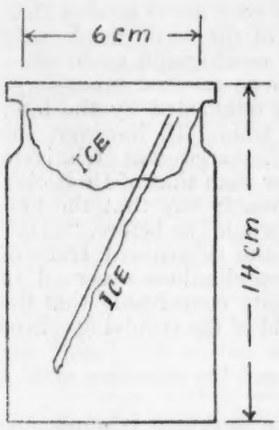

FIG. 7.—Test D with wide-mouthed bottle, showing "curtains" of ice suspended in the water, and saw-toothed blades extending far down into the water.

SUMMARY.

This paper deals with the formation of ice fringes upon the Dittany, *Cunila mariana*. The data here presented are based upon experiments and observations in the field and in the laboratory.

It was observed that the ice fringes are formed when the temperature falls to freezing; but they are not a function of the hoarfrost which may be present upon the ground.

The ice fringes do not form upon the side of a splinter which contains the pith or upon the line of fracture, but upon the outer woody surface. The formation of the ice fringe, however, is not a function of the surface condition of the stem. The stem is frequently found to be cracked, but usually no ice protrudes from the rifts.

The growth of the ice fringe ceases when the ground is frozen to a depth of 2 to 3 cm., and when the moisture in the stem is frozen.

The dimensions of the ice fringes and the height to which they extend above the ground depend upon the rate of evaporation from the stem, and upon the amount of moisture in the ground. Over 5 grams of ice may be formed upon a single plant during a single night.

Photographs are given of ice fringes formed upon stems which had been kept in the laboratory several months. They show that the ice may be formed upon stems without the roots. Hence the ice is not formed as a result of hydrostatic pressure exerted by the roots, which are perennial.

All the observations agree in showing that the moisture rises in the stem as the result of capillary attraction. The height (1 to 5 cm.) to which the moisture can rise within the stem is governed partly by the rate of evaporation from the surface.

Photomicrographs of thin sections of plants are given, which show the structure of stems of plants which do not form ice fringes; also photomicrographs of sections of stems of plants which form ice fringes. It is shown that those plants which form ice fringes the most readily and in the greatest abundance have the most sap tubes.

The ice fringe is a composite of a number of very thin ribbons. In the laboratory the formation of the ice fringe was observed from its very beginning. The first stage in the production of the ice fringe consists of a single row of fine hairlike filaments of ice. This row of ice filaments lengthens up and down the stem. The filaments increase in number, thus forming a solid wedge-shaped "tooth" of ice, which constitutes the second stage of development. In the third stage of development the wedge-shaped tooth of ice widens and increases in length, as the result of freezing of the water which continues to soak out of the stem.

There appears to be no difference between the formation of these ice fringes and the "ground ice" formed on wet soils other than that in the latter a particle of gravel usually forms the nucleus to start the congelation. In both cases the moisture is brought to the surface by capillary action. When the rate of supply to the surface is more rapid than the loss by evaporation, and the air is at a sufficiently low temperature, ice is formed.

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(4) **Elliot, Stephen.** Sketch of the botany of South Carolina and Georgia, 1824, v. **2**, p. 322. Quoted by Le Conte.

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(7) Ward quotes Gray's "Manual" of 1848, in which *Helianthemum canadense* is described as behaving in a similar way.

ARE LIGHTNING FLASHES UNIDIRECTIONAL OR OSCILLATING ELECTRIC DISCHARGES?[1]

By CHARLES F. MARVIN, Chief.

[Dated: Weather Bureau, Washington, D. C., June 13, 1914.]

L. A. De Blois, in making experiments upon electrical discharges in a wireless aerial (natural period 400,000) caused by neighboring lightning flashes, using for this purpose both a static voltmeter and an oscillograph whose behavior was photographed or examined by means of a revolving mirror, found only nearly instantaneous lateral flicks of the oscillograph needle. In some cases the needle showed a number of minor oscillations executed during the return of the needle to its zero position. The duration of a discharge of this kind was at least 0.0034 second. The periodic time of the oscillograph was 5,000 to 6,000 per second.

De Blois states that—

> In no records was there any indication of regular periodic high-frequency oscillations in the induced current. Had they existed, the

[1] This paper and the following comment refers to the preliminary edition of the paper by L. A. De Blois, "Some investigations on lightning protection for buildings," presented at 294th meeting Am. Instit. Elect. Eng., Washington, Apr. 24-25, 1914, and appearing as Trans. Am. Instit. Elect. Eng., 1914, **33**:563-579, and pl. 25. The illustrations of that paper are not reproduced here.—EDITOR.

oscillograph, of which the periodic time was 5,000 to 6,000, would have failed to respond. This was never the case with heavy discharges to earth near by, though it did happen,[2] presumably for other reasons, with many purely intercloud discharges. Moreover, the static voltmeter could hardly have been expected to respond to high-frequency oscillations as it did in the majority of cases of lightning discharges to earth. On the other hand, it is probable that the currents induced in the collector aerial followed in a general way at least the variations in the traveling waves of the lightning discharges, since such variations, judging by the oscillograms, involved high values of di/dt only in the case of steep-front waves, and also for the reason that the damping effect of the aerial, whose natural period of vibration was about 400,000, must have been very small. If such was the case, do not the records obtained point to the fact that lightning discharges are essentially unidirectional, nonoscillatory, aperiodic phenomena, especially since

FIG. 1.—Illustrating damped oscillations.

the steep wave-front occurring in the majority of such discharges would account for all the usual effects attributed to high-frequency oscillations?

While in the passage quoted the author asks the question if the observations cited do not indicate that lightning discharges are unidirectional, nevertheless elsewhere in his paper it is plain he concludes that the results seemingly "indicate that such currents *are* nonoscillatory and aperiodic."

The present writer is of the opinion that the behavior of the static voltmeter and also the oscillograph have been misunderstood and that the records and actions described by De Blois are not at all inconsistent with the assumption that lightning discharges may be the high-frequency periodic currents they have been commonly supposed to be. The writer does not mean to affirm that lightning discharges are necessarily oscillatory, but that De Blois's experiments, fairly interpreted, indicate that such discharges may be oscillatory, rather than aperiodic, as he concludes.

It is well known that the duration of a lightning flash is but a small fraction of a second. This is conclusively shown by De Blois's results. For the purposes of demonstration we may assume that a lightning discharge *is* an oscillatory current of high frequency, as has been claimed or admitted by a number of eminent authorities.

We must regard this periodic flow as very strongly damped, and if we had a proper oscillograph to depict such a current it should give us a familiar record of damped oscillations, as shown in figure 1.

During the whole interval of time represented by the first half-wave of the discharge, the oscillograph will be influenced by a powerful electrical surge that will be adequate to cause just such a sudden "flick" of the needle as described and recorded by De Blois. If the period of the damped train of waves was very much greater than the comparatively slow period of the oscillograph, only 5,000 to 6,000, we believe the oscillograph could show only a relatively feeble response to the first great surge of the discharge and would be unaffected by the later relatively feeble waves of the train. If, however, the frequency of the lightning discharge was relatively moderate, but still much greater than that of De Blois's oscillograph, may we not reasonably say that the first surge of the damped discharge would, as before, "flick" the needle to one side, while the subsequent train of waves would cause the minor oscillations observed to occur in some cases? It is quite conceivable that the minor oscillations seen by the aid of the revolving mirror may represent something in the nature of "beats" between the oscillating discharge and the vibrating system of the oscillograph.

The reasoning followed in the foregoing is applicable to the interpretations of the indications of the static voltmeter, and we believe the conclusion is justified that the results obtained by Mr. De Blois from the oscillograph and static voltmeter, in the study of lightning discharges, is not inconsistent with the supposition that such discharges are of a high-frequency damped periodic character.

UNITED STATES WEATHER BUREAU,
Washington, D. C., June 9, 1914.

CHIEF OF BUREAU:

SIR: My delay in replying to your request for a discussion of your note on the lightning flash was caused by a long wait for some promised data from the Bureau of Standards that bears on the subject.

The oscillograms obtained by Mr. De Blois indicate, it seems to me, that the electric discharges that caused them were either wholly unidirectional or else so strongly damped as to be prevailingly in one direction. The relatively long duration, 0.0015 second, roughly, of the individual discharges seems to preclude the idea of strong damping and, therefore, the assumption of oscillation of any kind.

There are several other arguments against the assumption that lightning discharges are alternating, among them the fact that oscillations are impossible if the resistance of the path is greater than about 200 ohms per kilometer. Such scanty information as I have been able to find on the resistance of flames and electric arcs indicates that the resistance of the lightning path probably is much greater than this limiting value.

Respectfully,

(Signed) W. J. HUMPHREYS,
Professor of Meteorological Physics.

The above remarks were also submitted, with a copy of Mr. L. A. De Blois's paper, to the Superintendent of the United States Naval Radio Service, and through him to the United States Bureau of Steam Engineering. The comments of that bureau are as follows:

[Second indorsement.]

UNITED STATES NAVAL BUREAU OF STEAM ENGINEERING,
August 8, 1914.

Subject: Lightning flashes, whether unidirectional or oscillatory.

1. The bureau has carefully considered the question submitted, but a press of urgent matters has delayed reply, and the same difficulty now

[2] We infer the author's expression "it did happen," is intended to mean the oscillograph failed to respond.—C. F. M.

stands in the way of a discussion at length. The bureau's general conclusions in their most conservative aspect can not be better expressed than in the words of Mr. Marvin in the paragraph beginning on page 500 "The present writer is of the opinion," and ending * * * "rather than aperiodic, as he concludes," of his paper attached, wherein he concludes, practically, that De Blois' proposition is not proved. With the whole of Mr. Marvin's paper the bureau concurs, and especially with the ingenious suggestion as to the possibility of something in the nature of "beats" between the oscillating discharge and the vibrating system of the oscillograph.

2. The description of De Blois's experiments leaves the bureau uncertain as to the exact arrangement of apparatus with which the oscillogram in figure 3 [not reproduced from De Blois] was obtained. If this record was obtained from a spark discharge *from the antenna* described on page 564 when excited by the oscillation transformer described on page 570, the bureau would be inclined to believe that his experiments indicate positively the probability of an oscillatory rather than a unidirectional character of lightning discharges.

3. The antenna described is a strong oscillator. De Blois himself speaks of it as having low damping. Its tendency, therefore, upon discharge is to effect this discharge through a long series of oscillations in its own natural period, irrespective of the method of excitation. If excited by impact it follows this tendency without hindrance. A unidirectional lightning flash would appear to afford ideal shock excitation, and since we know that the observed spark from the antenna is oscillatory in such a case the question arises "What is the behavior of the oscillograph under this condition?" This point appears to have been neglected in the experiments, though seemingly it might easily have been investigated by means of ordinary quenched gap excitation. Suppose we have investigated it and have found the oscillograph to give only sudden definite flicks like those in figure 3 [not reproduced from De Blois]. How then explain the succession of peaks such as those actually observed, as shown in figure 1 [not reproduced from De Blois]? Obviously either—

(1) As the result of "progressive breakdown" phenomena, described by Steinmetz, in which case the demonstration is still conclusive, or

(2) As the result of forced oscillations of long period or of mixed period, which is the same as saying that the lightning flash is oscillatory.

4. It appears to the bureau that nothing is to be deduced with certainty from this data until the behavior of the oscillograph is known when subjected to oscillatory discharges of different frequency and damping. With an instrument of such low periodicity as 5,000—6,000 too many unknown factors enter to allow a reasonable attempt to interpret the results except in the light of such experimentation.

Bureau of Steam Engineering.

THE ATMOSPHERE OF THE PLANET MARS.

The subject of the so-called canals on the planet of Mars has been carefully treated in a series of articles by Prof. William H. Pickering, published in Popular Astronomy in 1914. He finds that one may perceive similar canals on the moon if only its surface is examined under the same optical conditions used in the study of Mars. It may be worth while for the meteorologist to study the surface of the earth under similar conditions. He has only to represent on an artificial globe the portions that are water, snow, or ice; mountains, plateaus, or lowland; forests, prairies, or deserts, by a proper system of coloring; then place the globe at the proper distance and view it with the proper magnifying power through an atmosphere that is more or less hazy or undulating. The following extracts from Prof. Pickering's paper will show what could be expected under these conditions:

LUNAR CANALS.

The present report will be devoted chiefly to a study of the canals. By a canal in the astronomical sense of the word is meant any long, narrow dark marking that is straight, or of large radius of curvature and of fairly uniform breadth and density. The existence of the canals on Mars as objective realities must appear obvious to any one who has seen the planet under sufficiently favorable circumstances. They have been seen at this station [Mandeville, Jamaica, W. I.] with the 11-inch refractor by using a magnification of 660 when the diameter of the planet was but 5.6 inches. When well seen they can be held by the eye like any other real marking for indefinite periods. The main cause of the controversy regarding them is that in northern latitudes, where most of the large telescopes are located, the seeing is not sufficiently good to show them well, and their existence therefore continues to be doubted in some quarters.

Another cause of doubt depends on the mistaken idea still held by the public, and also by many astronomers, that the larger the telescope the more you can see with it. If the seeing were good enough, or if the objects were very faint, this would obviously be true. But even with double stars there is a limiting size of aperture giving the best results, depending on the quality of the seeing, and with bright planetary detail this limit is very marked indeed. The statement once made in joke that the 40-inch Yerkes lens is too powerful to show the canals of Mars is literally true. There are too many air waves constantly passing in front of its great surface to permit of the necessary planetary definition.

For our northeastern States the best results on a good night can be obtained with an 8-inch aperture. In the Southwest 16 inches is perhaps the limit. The proper size for the Tropics has not yet been reached by any instrument located there, and is still unknown. Any telescope intended for regular use on planetary detail should be provided with a cat's-eye diaphragm placed over the objective, which can be adjusted instantly from the eye end of the telescope, a device first used I believe at the Lowell Observatory.

As a means of studying the canals of Mars it occurred to the writer that since the moon is a body closely resembling it, and of the same order of size, if we were to apply to it the same magnification in proportion to its distance, that we might get a similar effect. The average distance of Mars at opposition is 50,000,000 miles, the average distance of the moon, one-quarter of a million. The moon being at one two-hundredths the distance of Mars, we should use one two-hundredths the magnification. The Martian canals are well seen with a power of 500. An ordinary opera glass giving a power of 2.5 would therefore be a proper instrument with which to view the moon. If we wish to have the moon appear of the same size as Mars, a field glass magnifying five times should be employed.

A preliminary sketch made with an opera glass on April 28, 1912, showed a number of long, narrow canals crossing the face of the moon. Of these the most conspicuous was the broad, double canal shown in figure 1 [not here reproduced] extending northwesterly from Tycho. Next came the three canals to the west of it and a few of those shown in Imbrium. All were narrow and quite uniform in appearance. The present sketch was made with a field glass magnifying four times, on October 14, 1913, colongitude 90°. The double canal extending from Tycho was now so broad that it had almost lost its canal-like character, but numerous fine canals appeared, among them several exceeding 400 miles in length. Only the more conspicuous ones have been drawn, in order to avoid confusing the sketch. When near the terminator the canals are faint or invisible. They seem to be most conspicuous when the moon is full, and individually to vary more or less with the colongitude. It would seem as if a detailed study of them might repay the careful observer. Perhaps the best results are obtained on a slightly hazy evening or with the moon not very far above the horizon, so it shall not be too dazzling. Even with an opera glass better results are obtained if it is steadied by holding it against a post. It is perhaps easier to see them in the first place with a field glass, but once seen, an opera glass gives them a more canal-like appearance. With the latter they are narrow, straight, and gray or black; with the former they show a slightly irregular structure, and at times are distinctly brownish. There are few canals on Mars more distinct than those between Copernicus and Aristarchus when seen under favorable conditions with an opera glass.

But it is not necessary to wait for a moonlight evening in order to see the lunar canal. The same result can be obtained, though in an inferior way, from any good photograph of the full moon. This should be placed against the wall in a strong light and viewed with the naked eye from a distance of between 20 and 40 times its diameter. If we get nearer than this we see that the lakes, with the exception of Plato, are not sharply defined regions, but simply small, dark areas of irregular shape and density, which are in reality much larger than they appear in the drawing. Similarly the canals, which are drawn as heavy, fine lines, are in reality broader and less intense areas of the same length. They vary in general from 20 to 60 miles in breadth. The effect is clearly not due to areas of irregularly distributed and imperfectly seen fine detail. The surface is not necessarily irregular in density nor spotted nor filled with any detail at all. All that is required to produce a canal is a comparatively slight difference in density, a reasonable breadth, and a sufficient intrinsic brilliancy to render it visible. * * *

A study of the lunar canals calls to our attention an unlooked-for characteristic. We should naturally expect that as we approached nearer and nearer to the photograph, or used higher and higher powers upon the moon, that while the canals first seen would be resolved and exhibited in their true aspect, that other finer canals would appear which a closer approach would in their turn resolve. On the moon, excepting with very low powers, this does not seem to be the case. It is true that with a power of several hundred diameters, short, uniform canals make their appearances, resembling in all respects the short,

stout canals in the Solis Lacus region of Mars (Harvard Annals, 53:75), but the long, narrow canals hundreds of miles in length, so characteristic of Mars, are seen on the moon only with such low powers as we have just described. It must be noted that in the case of these canals their size and appearance do not vary in any way with the aperture, but only with the magnification. Of this anyone can readily satisfy himself.

As we reduce the aperture of the field glass, a slight improvement in distinctness is noted when we reach a size of about one-fourth inch, on account of the reduction of the glare, but when the aperture gets below one-eighth or a magnification of 32 to the inch, they become less distinct again. They continue to remain visible and to be of the same breadth and in the same place until with failing light they gradually fade from view. * * *

The surface of Mars appears to be particularly well adapted to producing the canal effect. Only isolated areas upon the moon show it to advantage. This may be because the bright areas of the moon are too rough and the smooth areas too dark—for even on Mars the canal effect is conspicuous only in the bright regions. Again, on account of the more abundant vegetation on Mars, it is possible that stripes on the planet are more frequent, for it must be remembered that the basis of every canal is really a stripe, although the increase of blackness may be slight and the breadth great and irregular. The presence of lakes at the two ends of a canal will render it much more readily visible, though they will not produce a canal if there is no real shading between them. It might be suggested that a new and temporary canal on Mars might appear in any region if bounded on either side by a faint band of haze or cloud. At every opposition, by using the proper magnification, 300 to 600, some canals should be seen, and if they are not it merely indicates that the definition is inferior. The better the definition, quite regardless of the aperture of the telescope, the more clearly will the canals appear.

In our sketch of the moon the shape and location of the maria, and the positions of a considerable number of the bright craters are in fair agreement with what we know to be the case, as based on photographs and the use of higher telescopic powers. To the left and above the center of our figure, shaped like a letter F, are several short, thick canals and a number of lakes which are also in fair agreement with the facts. On the other hand, our long, thin canals give little or no information as to the real appearance of that portion of the surface. In spite of this fact the canals of Mars are well worth while observing, because they change with the seasons and also differ from year to year at the same season on Mars. This is perhaps the most artificial feature. If the observer desires to study them to the best advantage, then the only way to do so is to draw them as they appear. Sometimes many of them appear as straight, narrow, dark lines. The fact that they may not really be narrow or perfectly regular is no reason why they should not be carefully studied and named, and all honor should be given to Schiaparelli, who, although not their discoverer, was the first to observe them in large numbers and to draw general attention to their existence. Still, we must remember at their best they are only indications of detail, not the real thing. That is to say, what they indicate is something that is actually beyond the power of the observer's telescope to correctly define. * * *

The most striking difference between the lunar and Martian canals is that the latter are much more variable both in density and position, and often are entirely invisible. The former vary a little in density with the colongitude, which corresponds with the season upon the moon. Those lunar canals visible with a field glass we shall designate as the coarser canals; those visible in the telescope we shall call the finer ones. With the latter we have the same difficulty as in the case of Mars, they appear perfectly straight and uniform, and as we saw in our last report, in some cases they may even appear double. * * *

CONCLUSIONS.

It now only remains for us to draw whatever conclusions may seem probable with regard to these interesting objects, since it does not seem likely that any further light on their nature will be gained, at least as far as Mars is concerned, before the next opposition. It is believed that Lambert was the first to suggest that the reddish areas of Mars owed their color to vegetation. The suggestion that they were simply desert regions, while the dark areas and canals were due to vegetation instead of water, was of comparatively recent origin.[1]

The writer believes that both types of lunar, as well as the Martian canals, are due to vegetation. Indeed, no other explanation seems possible when we stop to consider the facts. It does not seem possible that the lunar canals can be artificial, but the Martian ones act differently from them in some respects, notably in their great variability, and if we may so express it, their apparently unnatural conduct, some appearing during one Martian year and others during another, at the same season. They act, indeed, almost as if there were some guiding intelligence behind them. Their uniform breadth, straightness, and occasional circular or elliptical forms are waived as arguments, because perhaps they are not really quite as regular as they appear, and because we find something very similar upon the moon. It is to other changes that we should especially direct our attention, and regarding which future observers should secure all possible data.

The Martian atmosphere, as far as its permanent constituents are concerned, we know to be more or less rarefied. The amount of water vapor it contains on the other hand, in the presence of ice or water, depends exclusively upon the temperature. When the polar caps are melting rapidly therefore, and large liquid surfaces present themselves in the marshes, the atmosphere may, at ordinary terrestrial temperatures, be composed in a very large part of water vapor. At other times it may contain very little. The question of the Martian seasons should be considered very carefully in any future attempts to detect the presence of water vapor by means of the spectroscope. One of the most careful and painstaking attempts hitherto made to secure evidence of the presence of water vapor upon Mars was made during the dry season upon the planet.

Assuming that the canals are due to vegetation, we must further assume either that they are or are not artificial. Assuming first that they are, we shall find that three attempts have hitherto been made to explain them.

(*a*) They were formerly supposed to be fertilized by invisible irrigating ditches or conduits. The difficulty with this idea is to maintain the necessary circulation of water. Prof. Lowell, when he adopted it, suggested that the circulation was maintained by pumping. To this it is replied that that would require altogether too great an expenditure of energy when the problem is reduced to figures. Indeed, the formation of the polar caps is sufficient of itself, as Prof. Douglass long ago pointed out, to show that the planetary circulation must be in large part atmospheric and not due, except at the very beginning, to artificial canals. If it is atmospheric in part it might as well be wholly so.

(*b*) It was suggested a few years ago [2] that the canals consisted simply of a growth of dark vegetation like trees or bushes upon grassy or semi-arid plains of a lighter color, all being supported by water derived from the natural aerial circulation of the planet. The beauty of this plan consists in its extreme simplicity, and the fact that such canals actually exist upon the earth on a small scale, constructed in this matter for good and sufficient reasons, though presumably not the same ones, namely protection for herds of cattle against winter storms. The difficulty, however, is to account for the shifting of the canals.

(*c*) In an atmosphere saturated with moisture, fogs should readily form at night, which would disappear to a large extent in the daytime. This frequently occurs at certain seasons, notably the early autumn, upon the earth. Since the surface of Mars seems to be extremely flat, it is suggested that these fogs instead of being permitted to exhibit a general accidental distribution, might be localized night after night in certain selected regions artificially. It is known as a laboratory experiment that fog can be induced to form in a saturated atmosphere if furnished with a sufficient number of minute solid nuclei on which it may condense. It is suggested that it might be practical to do this, either by electrifying the air in certain regions night after night, or by some such similar means upon a large scale on Mars. Where the fogs condensed at night vegetation would appear by daylight, when the fog cleared away. As a matter of observation, fog is often seen on the sunrise limb of the planet, and it does in general clear away as the sun rises higher upon it. Occasionally, however, it persists throughout the day, particularly near the northern boundary of certain dark areas, such as Sabaeus and Cerberus, as noted in our Report No. 3. A certain shifting of the fertilized areas from time to time would doubtless insure improved crops if the water supply were insufficient to fertilize the whole, so that we can readily see an object for it. If, on account of accelerated growth due to greater moisture, the vegetation ripened, dried up, and died first along the medial line of the canal, we can account for the apparent duplications sometimes observed. In our Report No. 4 we saw that marshes did actually appear to advance and change their positions in this manner, following clouds or fogs produced by evaporation from their surfaces.

The difficulty with this explanation is the question whether it would be possible in a saturated atmosphere overlying a uniform surface, to select any locality at will over which a fog should be produced.

Assuming now that the canals are due either to vegetation or to any other cause, but that they are *not* artificial, we find that to frame a plausible hypothesis that will explain the changes hitherto observed is a matter of extreme difficulty. The only natural agencies at our disposal capable of producing such changes seem to be either volcanic or meteorological. The latter appears to be the more promising, although many of the lunar canals lie along volcanic cracks. We may modify either (*b*) or (*c*) by substituting for intelligent design the accidental shifting of the winds, bringing more moisture and causing certain kinds of vegetation to flourish. To support a single canal 2,000 miles long by 500 miles wide would seem to require too much volcanic activity. Such suggestions involve added hypothesis and are, therefore, unsatisfactory. It may fairly be said that no satisfactory explanation,

[1] Science, 1888, 12: 82.

[2] Harper's Monthly Magazine, 1908, p. 192.

based on purely natural causes, has as yet been suggested to account for the changes observed on Mars.

It is not considered by the writer, however, that any of these hypotheses are sufficiently well supported as yet to justify us in such a momentous conclusion as the decision that intelligent animal life now exists upon Mars. To the majority of scientific men, probably nothing short of the reception of a series of intelligible signals would be considered sufficient evidence to lead to such a decision. These theories of the canals are mentioned here, not because the writer feels assured that any one of them is right, but simply because (*b*) and (*c*), at least seem to him to account for the observed facts more readily than any of the others, and because he feels that any theory, even a false one, is better than none at all. To the direct question so often asked, however, "Is Mars inhabited by intelligent beings?" we must, and probably long shall be obliged to reply simply, possible, but not proven.

DOES THE DARKEST HOUR COME JUST BEFORE DAWN?

This popular saying is frequently supposed to be poetical rather than meteorological. The well-known observer of meteors, Mr. W. F. Denning of Liverpool, in a note to The Observatory, as quoted in the Journal of the Royal Astronomical Society of Canada,[1] states that his own experience would confirm the truth of this proverb, and we quote his statement in full in the hope that American observers may throw light on the problem.

The darkest hour precedes the dawn.—I have occasionally seen inquiries as to the truth of this expression, but can not remember to have read any discussion or explanation of the subject.

Having been out observing on thousands of nights, and often enough "until the dappled dawn" rose, I may, perhaps, be allowed to give an opinion on the matter—and it is certainly in favor of the view stated in the heading to this note. I have frequently been impressed with the intense darkness which comes on before dawn. When a person has been out all night his eye naturally becomes accustomed to the prevailing conditions; he can discern things with astonishing distinctness and is familiar with such objects around as are within his range of vision.

Before dawn a greater darkness seems to drop down like a mantle upon the immediate surroundings. Objects which were plainly observable during the previous hours of the night are blotted out, and a nervous feeling is sometimes induced by the dense opacity of the air. I think the unusual darkness only lasts a short time, and that a quick brightening succeeds, but its occurrence is most marked and by no means a rare experience. I have noticed it independently of any previous knowledge, and when such a thing has been far from my thoughts, so it can not have been a subjective sensation. But I have been out only on clear, starry nights.

I regret that I have recorded no observations in detail, and so can not say the exact interval before sunrise when the remarkable darkness came on, and whether it is common to every night and season and condition of sky. But of its frequent manifestation I can speak with confidence, and possibly there may be some simple explanation of the event, though it does not occur to me at the moment.

NOTES ON BALLOON OBSERVATIONS AND ON WATERSPOUTS FROM THE VOYAGE OF LA PÉROUSE.

In the MONTHLY WEATHER REVIEW for October, 1898, **26**: 461–463, we have published all known references to the use of the kite, but Dr. Otto Klotz has sent us from Ottawa a note that is worth repeating from the original French text.

In the original Paris edition,[2] "Voyage de la Pérouse au Tour du Monde," v. 1, Paris, 1797, there have been collected in four quarto volumes all that pertains to the unfortunate expedition which started June, 1785, and was destroyed by a hurricane in 1788 among the islands northwest of Australia.

These four volumes embrace the personnel of those under La Pérouse, also the detailed orders of the King, Louis XVI, relative to the route of the expedition. Among the special observations relative to navigation those relating to the magnetic needle were prominent. Beginning with volume 1, page 156, of the quarto French edition of 1797 (or p. 222 of the octavo English edition of 1798) are given in detail the scientific objects suggested by the Academie des Sciences, as communicated by its eminent permanent secretary, De Condorcet, who was born in 1742 and died in 1794, a sacrifice to the troubles of that year.

Among the apparatus of the scientific outfit we note (p. 249, 1797 edition): "One large balloon of toile [either linen or cotton cloth] with an inner lining of thin paper (papier Joseph), 26 feet high and 22½ feet in diameter; also three balloons of paper and three of goldbeaters' skin." This outfit having been provided in 1785 seems to have contemplated the use of hydrogen gas, which was advocated for aeronautic use by the Paris Academy of Sciences in 1783, as being better than the Montgolfier [method], although the popularity of the latter had captivated the attention of all the world.

We translate as follows (p. 162, French edition; p. 122, English edition of 1799) from the suggestions by the Academy of Sciences:

> The academy on learning that the navigators are carrying with them a certain number of small aerostatic balloons invites them to make use of these in order to determine the altitude at which the winds that blow in the lower part of the atmosphere change their direction and also the course of these directions. These observations are especially important in localities where the trade wind prevails, where it will be desirable to know its relation with the winds of the upper region of the atmosphere * * *.

On page 163, we read:

> There is no agreement as to the cause that produces waterspouts (trombes) or tornadoes; some attribute them to electricity; others consider them as the effect of a turbination (twisting ascent) contracted by a mass of air.*
>
> Navigators should be very attentive to observations of all the circumstances that conduce to the explanation of this mysterious phenomenon.

This theory of the form and action of waterspouts is in many of its details so far in advance of anything that had been advocated by Andoque (1727); Franklin (1753); Cotte (1774), and others of that time, that we may properly attribute it to the distinguished permanent secretary of the Academy, Condorcet, whose thorough familiarity with the laws of mechanics expounded by Euler and whose remarkable insight into every branch of natural philosophy seems to warrant and justify our conclusion. Had not d'Alembert died in October, 1783, we should have thought this lucid explanation might have emanated from that distinguished philosopher. Doubtless the mechanics of tornadoes as we now understand it had been most carefully discussed by those eminent members of the Academy of Sciences, Condorcet, d'Alembert, La Place, and Benjamin Franklin who frequently attended its meetings during the years 1776–1785.—[C. A.]

[1] Toronto, July–August, 1914, **8**: 294–295.

[2] Published in accordance with the decree of Apr. 22, 1791, and edited by L. A. Millet-Mereau.

* In this latter hypothesis the centrifugal force of molecules of air forced from the axis of rotation should diminish the pressure of those that are located near the axis, forcing them to relinquish the water they hold in solution and to give rise to a cloud whose form will be very nearly that of a solid of revolution and whose little drops will soon disperse as the effect of centrifugal force. The pressure of atmospheric air not being diminished in the direction of the axis of rotation, the air should perpetually renew itself, entering at the two extremities of the axis and by the diminution of pressure maintain in the interior a continuous precipitation of water that will endure as long as the turbinate movement continues and whose abundance will depend on the velocity of that movement and of the mass of air it affects.

SECTION III.—FORECASTS.

STORMS AND WARNINGS FOR AUGUST.

By H. C. FRANKENFIELD, Professor of Meteorology.

[Dated Washington, D. C., Sept. 8, 1914.]

From the viewpoint of the forecaster the month was almost entirely featureless. There was the usual succession of low and high areas, none of them of unusual character, and they were attended by the usual alternations of fair and warmer weather and thunder showers and cooler weather. There was no occasion for storm warnings on any of the ocean coasts or any of the Great Lakes, except on the 5th, 22d, and 23d, when small-craft warnings were ordered. On the 5th there was a moderate depression just south of Nantucket, Mass., with a northeastward movement, and small-craft warnings were ordered for the New England coast. The disturbance passed off rapidly, however, and the winds were only fresh. On the 22d there was a well-marked disturbance central over Minnesota, and small-craft warnings were ordered for the following day for Lake Michigan, Superior, and northern Lake Huron. These were fully verified, and on the morning of the 23d small-craft warnings were extended to the balance of the lower Lakes with equally good verification following, the most severe winds occurring in the shape of thunder squalls on Lake Erie.

There were a few light frosts during the month from the northern upper Lake region eastward into northern New England, some of them forecast, but none was of consequence. There were also frosts on six different dates in northwestern Wyoming, those on the 24th, 25th, and 26th being heavy. There were also local frosts on the 26th in North Dakota, but frosts forecast for the 27th over the Northwestern States failed, as a rule, on account of the persistence of cloudy weather.

NORTHERN HEMISPHERE PRESSURE DISTRIBUTION.

Owing to the European war no reports have been received from Europe and Asia since July 31, and as a consequence the preparation of the Weekly Weather Forecast has been much hampered. These forecasts met with a fair measure of success during the first three weeks of the month, but the forecast for the fourth week was an almost total failure, except over the southern portions of the United States. There is no reason to expect any resumption of these reports until after the termination of the war.

Reports were received as usual from the Aleutian Islands, Alaska, and Honolulu, and these indicated for the Aleutians and Alaska a period of low pressure during the first and third decades of the month with a period of high pressure between, the principal crests occurring at Dutch Harbor on the 13th and at Nome on the 11th. The low pressures were not marked, except over Alaska, the greatest depressions occurring on the 27th. Pressure at Honolulu was below the normal during almost the entire month.

SECTION IV.—RIVERS AND FLOODS.

RIVERS AND FLOODS, AUGUST, 1914.

By ALFRED J. HENRY, Professor of Meteorology, in charge of River and Flood Division.

The rivers during August, 1914, with few exceptions, were at the usual midsummer stages. The exceptions were due to heavy local rains which appear to have been unusually effective in the rivers of Texas. The Trinity in its upper reaches, especially at Dallas, exceeded the flood stage by 2 and 5.2 feet, respectively, on the 17th and 30th. Sharp rises also occurred in the Guadalupe on the 8th and 9th; in the Brazos between the 14th and 21st; in the Colorado from the 17th to 20th and from the 26th to 31st. The Guadalupe was out of its banks at Victoria on the 8th and 9th, the Brazos at Waco on the 17th, the Colorado at Columbus on the 19th, 20th and 21st, and the Trinity in the vicinity of Fort Worth and Dallas from the 16th to 18th and from the 28th to 31st.

Flood waters caused but little damage along the trunk streams, however, as the lands overflowed were mostly used for grazing purposes, and live stock was removed upon receipt of warnings.

Heavy rains during the opening days of the month in the western part of Fremont County, Colo., resulted in a moderate freshet in the Arkansas from the 2d to the 4th. At Hot Springs a height of 10 feet was attained on the 2d; at Pueblo, 8.2 feet on the 3d; and at Fort Lyon, 5 feet on the 4th. No damage resulted in the Arkansas watershed, and in the other watersheds of the district there was no damage from floods.

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LAKE LEVELS DURING AUGUST, 1914.

By UNITED STATES LAKE SURVEY.

[Dated: Detroit, Mich., Sept. 2, 1914.]

The United State Lake Survey reports the stages of the Great Lakes for the month of August, 1914, as follows:

Data.	Lakes.			
	Superior.	Michigan-Huron.	Erie.	Ontario.
Mean level during August, 1914:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea level at New York	602.76	580.64	572.59	246.33
Above or below—				
Mean stage of July, 1914	+0.08	−0.10	−0.24	−0.39
Mean stage of August, 1913	−0.02	−0.58	−0.65	−0.98
Average stage for August, last 10 years	+0.10	−0.42	−0.12	−0.44
Highest recorded stage	−1.17	−2.87	−1.52	−1.93
Lowest recorded stage	+1.16	+0.79	+1.21	+1.98
Probable change during September, 1914	−0.1	−0.2	−0.3	−0.4

SECTION V.—BIBLIOGRAPHY.

RECENT ADDITIONS TO THE WEATHER BUREAU LIBRARY.

C. FITZHUGH TALMAN, Professor in charge of Library.

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C. FITZHUGH TALMAN, Professor in charge of Library.

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SECTION VI.—WEATHER AND DATA FOR THE MONTH.

THE WEATHER OF THE MONTH.

P. C. DAY, Climatologist and Chief of Division.

Pressure.—The distribution of the mean atmospheric pressure over the United States and Canada, and the prevailing directions of the winds, are graphically shown on Chart VII, while the average values for the month at the several stations, with the departures from the normal, are shown in Tables I and III.

For the month as a whole, the mean barometric pressure was above the normal over the greater portion of the country, the plus departures being rather marked in the South Atlantic, Gulf, and Pacific Coast States, but elsewhere they were, as a rule, small. The only districts in which the monthly values were below the normal appear in the region of the Great Lakes, the middle and upper Mississippi and lower Missouri valleys, and in the northern Plateau region, where the means for the month were below the average, though no marked minus departures appeared in any portion of the country.

During the first few days of the month unsettled barometric conditions obtained throughout the country, with no well defined low or high area. About the 4th a depression of some consequence advanced southeastward from the Canadian Northwest and moved eastward along the northern border and down the St. Lawrence Valley during the following few days, but with decreasing intensity.

About the beginning of the second decade another disturbance of moderate intensity moved eastward over the northern border States, and was followed by an area of moderately high pressure which extended southward and covered all eastern districts about the 12th and 13th. From this time to the beginning of the third decade no important pressure changes occurred, but the tendency was to relatively high readings in southern districts and lower pressure to the northward.

After the middle of the third decade a disturbance passed from the Southwest northeastward across the country to the Canadian Maritime Provinces, and the month closed with low pressure over the Plateau region and a depression of marked character advancing southeastward over the valley of the Red River of the North, while relatively high barometric readings obtained over eastern and southern districts.

The distribution of the highs and lows was favorable for the frequent occurrence of southerly winds from the Plains States eastward, while the prevailing directions to the westward were variable.

Temperature.—At the beginning of the month there was a general, though not decided, rise in temperature over eastern and southern districts, and warm weather continued in the West and Northwest, the temperatures being abnormally high in portions of the northern Rocky Mountain region and the adjoining Canadian Provinces. Near the close of the first decade relatively high pressure prevailed over the southeastern States and low pressure to the northward, causing southerly winds and high temperatures in the great central valleys and throughout the South. However, within a few days cooler weather advanced rapidly from the Mountain region of the West over the northern tier of States to New England, but it continued rather warm in southern districts and portions of the West.

About the middle of the month temperatures became high in the far Northwest and the warm area advanced eastward during the following few days, with maximum temperatures near or slightly above 100° in portions of the Dakotas, and at points to the eastward the previous high temperature records for August were equaled or exceeded.

Early in the third decade high pressure moved southward from Canada, and much cooler weather obtained from the Lake region westward, with minimum temperatures near the freezing point along the northern shore of Lake Superior on the morning of the 24th, and with light frost in extreme northern Michigan and at exposed points in Wyoming. During the following few days the cool area moved eastward and southward, giving temperatures below the seasonal average over the larger part of the country, and further frosts occurred in the more northern districts. During the last few days of the month there was a gradual change to warmer weather, except in the far Northwest where the pressure was rising and a decided fall in temperature had set in as the month closed.

The mean temperature for the month as a whole was above the normal in all districts east of the Mississippi River and in the central Plains States. Like temperature conditions obtained for the preceding month over much of these sections, but the departures were somewhat less marked for the month just closed, only a comparatively small area in the central Mississippi Valley showing plus departures as large as 3°. In the upper Mississippi Valley, the northern Plains States, the Rocky Mountain region and in California the means were less than the normal, but, like the plus departures, the values were generally small, reaching 3° only in limited areas. In the far Northwest and in the Southwest the means were near the normal for the month.

Precipitation.—During the first few days of the month unsettled, cloudy weather prevailed over much of the country, with local rains in most eastern districts. By the 5th a disturbance that had advanced from the Canadian Northwest had reached the central and northern plains States and showers occurred in that region, extending southward during the following few days over Kansas, Oklahoma, and Texas, the rainfall being particularly heavy in portions of the last-named State, where heavy falls continued for several days. By the close of the first decade the severe drought that had persisted in the Southwest had effectually been broken and quite general showers had occurred over most of the eastern half of the country, save in the Northeastern States and the middle Mississippi Valley.

At the beginning of the second decade showers continued over much of the country east of the Mississippi River, with heavy falls in the lake region and generous amounts in portions of the Ohio Valley where drought had prevailed, and at the same time showers occurred in portions of the plains States and the mountain region of the West. The decade was marked by unsettled weather, but as it advanced showers became less frequent.

During the third decade showery weather was again the rule over most eastern districts, the rainfall becoming more general near the end of the month as a low pressure area moved from the Rio Grande Valley northeastward across the country to New England, giving substantial to heavy rains over large areas and relieving the drought that had prevailed in the eastern sections of the corn belt.

For the month as a whole the rainfall was heavy, ranging from 6 to 8 inches, or more, in nearly all the Southern States, and generous amounts, ranging from 4 to 6 inches, were received from the middle Mississippi Valley eastward and northeastward to the Atlantic Coast. The monthly totals ranged from 2 to 4 inches over much of the Mountain region of the West and the central and northern Plains States, but in portions of the latter districts the amounts were light, ranging from 1 to 2 inches. No rain occurred during the month in the Pacific Coast States, and at the close drought had become severe in the northern portions.

GENERAL SUMMARY.

The most noteworthy features of the weather for August, 1914, were the generous amounts of rainfall in large sections of the principal crop-producing areas, thoroughly relieving the drought that had persisted in many localities, and the comparatively equable distribution of temperature over those districts.

The severe drought in the western section of the cotton belt was effectually relieved early in the month; the growing cotton rapidly responded to the favorable change in conditions, and by the end of the month it had recovered more than the previous deterioration from lack of moisture. Likewise the rainfall in the central and eastern portions of the belt was more generous than during the preceding month, and with favorable temperature conditions a general improvement in the condition of cotton and other crops was noted in those districts.

Later in the month good rains were received in large portions of the corn belt, especially in the central Mississippi Valley and to the eastward, which improved the general outlook and benefited the late crop, but in other portions of the belt droughty conditions continued and much early corn was damaged.

In the spring-wheat belt dry, hot weather caused considerable damage early in the month to the growing crop, but later these conditions were favorable for harvesting, and thrashing of the winter-wheat crop was accomplished without material interruption.

Over the great range country of the Southwest sufficient moisture was received to maintain the grass in good condition, but in the far Northwest the drought had become severe at the close of the month and grass and other vegetation were suffering for moisture.

Average accumulated departures for August, 1914.

Districts.	Temperature.			Precipitation.			Cloudiness.		Relative humidity.	
	General mean for the current month.	Departure for the current month.	Accumulated departure since Jan. 1.	General mean for the current month.	Departure for the current month.	Accumulated departure since Jan. 1.	General mean for the current month.	Departure from the normal.	General mean for the current month.	Departure from the normal.
	°F.	°F.	°F.	Ins.	Ins.	Ins.			P. ct.	P. ct.
New England	67.2	+0.1	− 9.5	3.26	−0.60	− 2.80	6.2	+1.2	84	+2
Middle Atlantic	74.0	+1.4	− 1.1	3.80	−0.60	− 3.40	5.5	+0.4	77	+6
South Atlantic	79.0	+1.2	+ 4.2	4.77	−1.40	−10.80	6.2	+1.0	83	+1
Florida Peninsula	82.7	+0.7	− 2.6	3.57	−3.40	−11.70	4.8	−0.4	74	−5
East Gulf	79.4	+0.2	+ 3.2	5.98	+1.10	− 5.50	6.2	+1.0	84	+4
West Gulf	80.6	−0.4	+ 3.9	5.94	+3.00	− 3.80	6.1	+2.1	80	+5
Ohio Valley and Tennessee	75.5	+0.7	+ 2.7	5.19	+1.80	− 5.60	5.5	+1.0	73	+1
Lower Lakes	70.1	+0.4	− 6.3	4.66	+1.70	+ 0.20	5.0	+0.4	72	+1
Upper Lakes	66.7	+0.4	+ 2.9	3.77	+0.80	+ 1.10	5.1	+0.4	76	+1
North Dakota	64.2	−2.6	+11.8	2.25	+0.80	+ 3.20	5.0	+1.0	70	+6
Upper Mississippi Valley	74.5	+1.6	+14.0	3.66	+0.40	− 5.20	4.9	+0.7	67	−3
Missouri Valley	75.2	+1.4	+18.6	2.75	−0.60	− 3.00	4.2	+0.1	65	−2
Northern slope	66.2	−0.6	+15.6	1.54	+0.30	− 1.60	4.3	+0.4	54	+2
Middle slope	76.4	+1.1	+16.9	2.40	0.00	− 3.40	4.2	+0.4	63	+4
Southern slope	78.3	−0.8	+ 5.7	5.93	+3.80	+ 4.40	4.6	+0.7	68	+7
Southern Plateau	77.4	0.0	+ 1.9	0.93	−0.20	− 0.60	2.7	−1.0	47	+5
Middle Plateau	72.4	+0.8	+ 9.2	0.50	−0.20	+ 0.20	2.5	−0.8	34	+1
Northern Plateau	71.5	+1.2	+18.5	0.02	−0.40	− 0.90	2.6	+0.3	34	−9
North Pacific	60.8	−0.2	+13.2	0.20	−0.60	− 0.30	4.3	−0.3	75	+8
Middle Pacific	64.6	−0.3	+ 6.4	0.00	0.00	− 0.40	3.5	−0.1	62	−5
South Pacific	69.8	−0.7	+13.0	0.00	0.00	+ 3.80	2.8	0.0	66	0

Maximum wind velocities, August, 1914.

Stations.	Date.	Velocity.	Direction.	Stations.	Date.	Velocity.	Direction.
		Mi./hr.				Mi./hr.	
Block Island, R. I.	17	61	w.	New York, N. Y.	21	51	nw.
Buffalo, N. Y.	10	54	w.	Sandusky, Ohio	23	52	nw.
El Paso, Tex.	10	55	ne.	Sioux City, Iowa	4	52	nw.
Jacksonville, Fla.	14	50	sw.	Toledo, Ohio	10	54	sw.
Modena, Utah	16	50	sw.	Do	23	55	nw.

CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data, as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course the number of such records is smaller than the total number of stations.

Summary of temperature and precipitation, by sections, August, 1914.

Section.	Temperature—in degrees Fahrenheit.							Precipitation—in inches and hundredths.					
	Section average.	Departure from the normal.	Monthly extremes.					Section average.	Departure from the normal.	Greatest monthly.		Least monthly.	
			Station.	Highest.	Date.	Station.	Lowest.	Date.			Station.	Amount.	Station.	Amount.
Alabama	79.1	— 0.6	Decatur	105	19	2 stations	59	30	6.41	+ 1.61	Robertsdale	12.89	Opelika	1.93
Arizona	79.9	+ 1.1	Sentinel	118	3	Fort Valley	36	31	2.11	— 0.35	Chiarsons Mill	9.41	4 stations	0.00
Arkansas	78.5	— 0.8	Newport	104	3	2 stations	57	6†	6.81	+ 3.19	Arkadelphia	13.74	Lewisville	2.82
California	72.1	— 0.7	Mojave	118	5	Greenville	24	19†	0.02	— 0.06	Cuyamaca	1.33	238 stations	0.00
Colorado	64.8	— 0.7	Wray	108	17	Dillon	25	13	1.99	+ 0.09	Steamboat Springs	5.36	2 stations	0.45
Florida	81.7	+ 0.6	Federal Point	101	8	Hilliard	60	1	5.70	— 1.72	Pinellas Park	11.51	Merritts Island	0.99
Georgia	79.1	— 0.2	3 stations	99	15†	Blue Ridge	55	16†	5.99	+ 0.39	Quitman	10.30	Hartwell	2.60
Hawaii (for July)	74.1	.....	Kaanapali, Maui	93	16	Honomanu Valley, Maui.	52	23	11.30	.....	Hakalau (Mauka), Hawaii.	62.26	Waiopae Ranch, Maui.	0.00
Idaho	66.8	+ 0.6	Kooskia	109	14	2 stations	24	18†	0.16	— 0.42	Burke	1.30	19 stations	0.00
Illinois	76.0	+ 1.7	2 stations	104	6†	Lanark	42	15	3.43	+ 0.22	Olney	8.28	Equality	0.71
Indiana	74.6	+ 0.8	Hickory Hill	102	22	2 stations	46	5†	4.73	+ 1.44	Paoli	8.05	2 stations	2.40
Iowa	73.7	+ 1.9	Lamoni	103	18	2 stations	40	14†	2.19	— 1.49	Lake Park	4.90	Webster City	0.42
Kansas	78.2	+ 1.0	Alton	108	17	Wallace	47	30	3.31	+ 0.07	Oswego	8.17	Lakin	0.64
Kentucky	76.0	+ 0.3	3 stations	100	2†	3 stations	49	1†	5.94	+ 2.59	Alpha	10.29	Franklin	2.86
Louisiana	80.8	— 1.1	Liberty Hill	106	1	Minden	59	1	7.48	+ 2.84	Lawrence	14.45	St. Gabriel	3.91
Maryland and Delaware	74.7	+ 1.2	Green Spring Furnace, Md.	102	8	Deer Park, Md.	38	16	4.73	+ 0.37	Annapolis, Md.	9.31	Salisbury, Md.	1.57
Michigan	67.3	+ 0.8	2 stations	100	8†	Watersmeet	29	24	3.91	+ 1.20	Olivet	8.64	Whitefish Point	1.70
Minnesota	66.1	— 0.4	Tracey	101	8	2 stations	29	24†	3.97	+ 0.37	Minneapolis (1)	8.92	Wheaten	1.34
Mississippi	79.8	— 0.6	2 stations	99	11†	Charleston	58	1	6.75	+ 2.65	Columbus	12.02	Bay St. Louis	3.04
Missouri	78.0	+ 1.8	Steffenville	106	7	Unionville	49	11	4.25	+ 0.60	Mexico	8.31	Oregon	1.16
Montana	63.6	— 0.6	2 stations	105	3†	Bowen	15	19	0.95	— 0.25	Babb	4.06	4 stations	0.00
Nebraska	73.8	+ 0.9	2 stations	109	16†	2 sections	39	10†	2.69	— 0.09	Grand Island	7.52	Mitchell	0.29
Nevada	72.5	+ 0.2	Leeland	122	12†	Geyser	14	18†	0.14	— 0.22	San Jacinto	0.90	15 stations	0.00
New England	67.2	+ 0.2	Cornwell, Vt	96	10	Bloomfield, Vt	32	25	3.69	— 0.15	Franklin, N. H	8.50	Patten, Me	1.00
New Jersey	73.3	+ 1.3	4 stations	98	19†	Culvers Lake	42	26	3.15	— 1.87	Woodbine	6.53	Hightstown	1.04
New Mexico	70.1	— 1.0	Artesia	105	1	Elizabethtown	20	28	2.34	— 0.02	Anchor Mine	7.77	Cundiyo	0.25
New York	67.7	+ 0.7	Fayetteville	103	9	Gabriels	30	25	4.76	+ 1.02	Fayetteville	8.01	Setauket	1.56
North Carolina	76.8	+ 1.0	Greensboro	101	19	Banners Elk	45	31	4.65	— 1.31	Parkersburg	9.85	Rocky Mount	0.80
North Dakota	64.2	— 1.3	4 stations	101	3†	3 stations	26	26	2.18	— 0.14	Energy	5.06	McLeod	0.64
Ohio	72.8	+ 1.4	2 stations	101	19	Akron	41	26	5.08	+ 1.78	Waverly	9.26	Thurman	2.88
Oklahoma	79.6	— 1.0	Newkirk	110	1	Kenton	46	26	5.78	+ 2.76	Durant	12.52	Kenton	0.68
Oregon	66.7	+ 1.4	Blalock	109	13	Cliff	20	17	0.03	— 0.59	Gardners Ranch	0.70	64 stations	0.00
Pennsylvania	71.3	+ 1.3	Hyndman	100	19	West Bingham	34	4	3.85	— 0.32	Wilkes-Barre	7.20	Pocono Pines	0.64
Porto Rico	78.6	— 0.5	Dorado	101	7	2 stations	55	2†	5.76	— 2.01	Lares	14.03	Hacienda Isadora	0.50
South Carolina	79.0	+ 0.2	Allendale	101	28†	Heath Springs	56	1	5.88	— 0.44	Smiths Mills	13.70	Gaston Shoals	2.52
South Dakota	69.5	— 0.5	Murdo	109	7	Eureka	29	26	1.99	— 0.50	Wentworth	4.84	Harveys Ranch	0.25
Tennessee	77.0	+ 0.7	Clarksville	103	2	2 stations	45	15†	5.85	+ 2.20	Johnsonville	13.70	Chattanooga	2.84
Texas	81.0	— 1.7	Brownwood	110	1	3 stations	50	24†	6.37	+ 4.55	Abilene	15.70	Santa Gertrudes	0.00
Utah	70.5	0.0	Springdale	109	15	Scofield	27	23	0.41	— 0.54	Trout Creek	3.62	14 stations	0.00
Virginia	75.0	+ 1.2	Woodstock	102	19	Emory	46	1†	3.24	— 1.38	Speers Ferry	9.25	Danville	0.87
Washington	66.5	+ 0.9	Colfax	113	2	Newport	25	31	0.10	— 0.73	Quiniault	1.12	40 stations	0.00
West Virginia	71.8	+ 0.3	3 stations	100	20†	4 stations	40	16†	4.86	+ 1.24	Bens Run	9.29	Upper Tract	1.38
Wisconsin	67.1	+ 0.2	Osceola	100	8	Long Lake	31	24	4.13	+ 0.47	Minocqua	8.49	Racine	0.88
Wyoming	62.4	+ 0.1	Wheatland	109	8	Willow Creek Cabin	17	17	0.76	— 0.09	Burns	4.45	2 stations	0.00

DESCRIPTION OF TABLES AND CHARTS.

Table I gives the data ordinarily needed for climatological studies for about 158 Weather Bureau stations making simultaneous observations at 8 a. m. and 8 p. m., seventy-fifth meridian time daily, and for about 41 others making only one observation. The altitudes of the instruments above ground are also given.

Table II gives a record of precipitation, the intensity of which at some period of the storm's continuance equaled or exceeded the following rates:

Duration (minutes)	5	10	15	20	25	30	35	40	45	50	60
Rates per hour (inches)	3.00	1.80	1.40	1.20	1.08	1.00	0.94	0.90	0.87	0.84	0.80

It is impracticable to make this table sufficiently wide to accommodate on one line the record of accumulated falls that continue at an excessive rate for several hours, In such cases *the record is broken at the end of each 50 minutes*, the accumulated amounts being recorded on successive lines until the excessive rate ends.

At stations where no storm of sufficient intensity to entitle it to a place in the full table has occurred, the greatest precipitation of any single storm has been given, also the greatest hourly fall during that storm.

Table III gives, for about 30 stations of the Canadian Meteorological Service, the means of pressure and temperature, total precipitation and depth of snowfall, and the respective departures from normal values, except in the case of snowfall.

Chart I.—Hydrographs for several of the principal rivers of the United States.

Chart II.—Tracks of centers of high areas; and

Chart III.—Tracks of centers of low areas. The roman numerals show the chronological order of the centers. The figures within the circles show the days of the month;

the letters *a* and *p* indicate, respectively, the observations at 8 a. m. and 8 p. m., seventy-fifth meridian time. Within each circle is also given (Chart II) the last three figures of the highest barometric reading and (Chart III) the lowest reading reported at or near the center at that time, and in both cases as reduced to sea level and standard gravity.

Chart IV.—Temperature departures. This chart presents the departures of the monthly mean temperatures from the monthly normals. The normals used in computing the departures were computed for a period of 31 years (1873 to 1903) and are published in Weather Bureau Bulletin "R," Washington, 1908. The shaded portions of the chart indicate areas of positive departures and unshaded portions indicate areas of negative departures. Generalized lines connect places having approximately equal departures of like sign. This chart of monthly temperature departures in the United States was first published in the MONTHLY WEATHER REVIEW for July, 1909.

Chart V.—Total precipitation. The scale of shades showing the depth is given on the chart. Where the monthly amounts are too small to justify shading, and over sections of the country where stations are too widely separated or the topography is too diversified to warrant reasonable accuracy in shading, the actual depths are given for a limited number of representative stations. Amounts less than 0.005 inch are indicated by the letter T, and no precipitation by 0.

Chart VI.—Percentage of clear sky between sunrise and sunset. The average cloudiness at each Weather Bureau station is determined by numerous personal observations between sunrise and sunset. The difference between the observed cloudiness and 100 is assumed to represent the percentage of clear sky, and the values thus obtained are the basis of this chart. The chart does not relate to the nighttime.

Chart VII.—Isobars and isotherms at sea level and prevailing wind directions. The pressures have been reduced to sea level and standard gravity by the method described by Prof. Frank H. Bigelow on pages 13–16 of the REVIEW for January, 1902. The pressures have also been reduced to the mean of the 24 hours by the application of a suitable correction to the mean of the 8 a. m. and 8 p. m. readings at stations taking two observations daily, and to the 8 a. m. or the 8 p. m. observations, respectively, at stations taking but a single observation. The diurnal corrections so applied will be found in the Annual Report of the Chief of the Weather Bureau, 1900–1901, volume 2, Table 27, pages 140–164.

The isotherms on the sea-level plane have been constructed by means of the data summarized in chapter 8 of volume 2 of the annual report just mentioned. The correction $t_0 - t$, or temperature on the sea-level plane minus the station temperature as given by Table 48 of that report, is added to the observed surface temperature to obtain the adopted sea-level temperature.

The prevailing wind directions are determined from hourly observations at the great majority of the stations; a few stations having no self-recording wind direction apparatus determine the prevailing direction from the daily or twice-daily observations only.

Chart VIII.—Total snowfall. This is based on the reports from regular and cooperative observers and shows the depth in inches and tenths of the snowfall during the month. In general, the depth is shown by lines inclosing areas of equal snowfall, but in special cases figures are also given.

Chart VIII is published only when the general snow cover is sufficiently extensive to justify its preparation.

TABLE I.—*Climatological data for United States Weather Bureau stations, August, 1914.*

Districts and stations.	Elevation of instruments.			Pressure in inches.			Temperature of the air, in degrees Fahrenheit.										Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation, inches.			Wind.						Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Barometer above sea level, feet.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max. + mean min. ÷ 2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.					Total.	Departure from normal.	Days with 0.01 or more.	Total movement, miles.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.	Clear days.	Partly cloudy days.	Cloudy days.			
New England.							67.2	+ 0.1											84	3.26	− 0.6									6.2		
Eastport	76	67	85	29.92	30.00	+0.04	59.8	+ 0.1	77	16	67	46	26	53	24	55	53	81	2.54	− 0.7	10	5,924	s.	38	e.	30	5	13	13	6.8	.....	.....
Greenville	1,070	6	.....	28.86	30.01	.....	61.9	.....	83	7	72	42	26	51	33	.....	.....	.....	.....	2.90	.....	11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Portland, Me	103	82	117	29.90	30.02	+ .04	64.1	− 2.1	81	15	71	47	28	57	23	59	57	81	3.81	+ 0.2	17	5,364	sw.	27	w.	14	6	10	15	6.8	.....	.....
Concord	288	70	79	29.71	30.01	+ .03	66.7	+ 0.1	91	10	77	43	26	57	31	.....	.....	.....	.....	5.91	+ 2.2	12	2,822	nw.	23	w.	14	5	16	10	5.8	.....	.....
Burlington	404	11	48	29.57	29.99	+ .02	66.0	− 0.1	94	10	76	40	26	56	34	.....	.....	.....	.....	2.78	− 1.2	13	6,282	s.	33	s.	23	7	14	10	5.6	.....	.....
Northfield	876	12	60	29.08	30.02	+ .04	62.6	− 0.3	91	10	75	34	26	50	35	59	58	86	3.14	− 0.8	16	4,268	s.	24	sw.	23	4	18	9	6.4	.....	.....
Boston	125	115	188	29.88	30.01	+ .02	70.4	+ 1.5	90	10	78	55	25	63	26	65	62	81	3.20	− 0.8	11	6,031	sw.	22	nw.	22	7	10	14	6.3	.....	.....
Nantucket	12	14	90	30.01	30.02	+ .03	67.6	− 0.4	84	19	74	53	26	62	16	64	64	93	4.42	+ 1.4	11	9,702	sw.	41	sw.	17	4	19	8	5.8	.....	.....
Block Island	26	11	46	29.99	30.02	+ .03	67.8	− 0.9	84	19	73	57	25	63	16	65	64	89	3.71	+ 0.2	11	9,759	sw.	61	w.	17	8	8	15	6.4	.....	.....
Narragansett Pier	.....	9	.....	.....	.....	.....	68.5	0.0	85	24	75	52	27	62	20	.....	.....	.....	.....	4.13	.....	13	.....	sw.	.....	.....	.....	17	4	10	.....	.....	.....
Providence	160	215	251	29.85	30.02	+ .03	70.2	− 0.8	90	9	78	52	27	62	24	65	62	81	2.02	− 2.0	11	6,974	sw.	48	nw.	21	8	11	12	6.0	.....	.....
Hartford	159	122	140	29.84	30.01	+ .02	71.2	+ 2.3	92	9	80	53	26	63	25	65	63	80	1.96	− 2.6	11	4,415	s.	24	sw.	21	7	13	11	6.2	.....	.....
New Haven	106	117	155	29.90	30.01	+ .02	71.7	+ 1.6	89	19	80	55	26	64	23	66	64	80	2.36	− 2.6	11	5,344	s.	29	sw.	11	7	14	10	5.6	.....	.....
Middle Atlantic States.							74.0	+ 1.4											77	3.80	− 0.6									5.5		
Albany	97	102	115	29.89	29.99	+ .01	71.3	+ 1.8	93	8	80	51	25	62	30	64	61	74	5.30	+ 1.3	15	4,388	s.	28	nw.	11	11	9	11	5.3	.....	.....
Binghamton	871	10	69	29.09	30.00	+ .01	68.7	+ 1.2	93	9	79	44	4	58	34	.....	.....	.....	.....	5.50	+ 2.2	14	2,720	nw.	26	nw.	20	6	15	10	5.9	.....	.....
New York	314	414	454	29.68	30.01	+ .01	73.7	+ 1.5	95	19	81	59	1	66	22	67	64	77	2.18	− 2.4	9	8,925	sw.	51	nw.	21	2	15	14	6.9	.....	.....
Harrisburg	374	94	104	29.63	30.02	+ .01	73.6	+ 1.5	93	19	82	60	3	65	26	66	62	71	4.43	+ 0.2	9	3,394	s.	40	w.	20	5	16	10	6.3	.....	.....
Philadelphia	117	123	190	29.90	30.02	+ .02	76.2	+ 2.4	94	19	84	61	1	68	23	69	66	75	2.31	− 2.3	11	6,215	sw.	31	sw.	21	6	14	11	6.3	.....	.....
Reading	325	81	98	29.68	30.02	.....	73.9	.....	94	9	83	59	14	65	27	67	63	74	3.13	− 1.4	9	3,690	se.	23	nw.	21	4	4	13	6.7	.....	.....
Scranton	805	111	119	29.18	30.03	+ .03	70.8	+ 1.5	92	9	81	50	4	61	28	65	62	78	2.56	− 1.7	12	3,817	s.	34	sw.	10	5	19	7	5.7	.....	.....
Atlantic City	52	37	48	29.97	30.02	+ .02	73.6	+ 1.0	92	24	79	61	1	68	22	69	67	83	4.72	+ 0.4	12	5,209	sw.	20	w.	3	7	16	8	5.3	.....	.....
Cape May	18	13	49	30.03	30.05	+ .05	74.1	+ 0.7	94	24	80	58	26	68	24	.....	.....	.....	.....	4.59	+ 0.3	11	5,100	s.	24	s.	17	12	14	5	4.5	.....	.....
Trenton	190	159	183	29.81	30.01	.....	74.4	.....	95	19	84	58	27	65	26	67	64	77	1.63	− 3.7	7	6,444	sw.	38	nw.	2	7	14	10	5.9	.....	.....
Baltimore	123	100	113	29.90	30.02	+ .01	77.0	+ 2.3	97	19	83	57	25	68	26	68	65	73	6.74	+ 2.5	12	4,361	s.	21	n.	2	8	14	9	5.3	.....	.....
Washington	112	62	85	29.90	30.02	+ .01	76.4	+ 1.9	97	19	86	58	26	66	32	69	66	77	6.00	+ 1.6	10	3,542	s.	32	nw.	21	10	13	8	5.1	.....	.....
Lynchburg	681	153	188	29.30	30.02	.00	76.3	+ 1.5	98	19	87	58	1	66	31	68	65	74	2.60	− 1.6	10	4,005	w.	38	nw.	12	11	16	4	5.0	.....	.....
Mount Weather	1,725	10	75	28.24	30.01	.00	71.2	+ 1.8	91	19	78	52	26	64	20	63	59	72	3.55	− 0.1	11	8,262	nw.	34	nw.	29	2	15	14	7.1	.....	.....
Norfolk	91	170	205	29.95	30.05	+ .05	78.2	+ 1.5	95	24	86	61	1	71	22	72	70	83	1.10	− 4.9	9	7,855	sw.	36	sw.	29	9	13	9	5.4	.....	.....
Richmond	144	11	52	29.89	30.04	+ .03	77.6	+ 0.1	101	24	88	57	1	68	28	70	67	78	2.42	− 2.0	12	4,942	s.	35	sw.	10	17	9	5	4.2	.....	.....
Wytheville	2,293	40	47	27.73	30.04	+ .03	71.4	+ 0.9	91	19	82	49	1	60	35	65	63	84	5.83	+ 1.3	12	2,565	w.	18	w.	21	16	13	2	3.3	.....	.....
South Atlantic States.							79.0	+ 1.2											83	4.77	− 1.4									6.2		
Ashville	2,255	70	84	27.78	30.07	+ .05	72.2	+ 1.7	88	20	82	57	6	62	28	65	63	84	5.48	+ 0.7	16	3,743	s.	33	s.	10	4	20	7	5.6	.....	.....
Charlotte	773	68	76	29.24	30.06	+ .04	77.7	+ 1.1	93	19	86	65	2	69	23	70	68	82	2.25	− 3.3	12	4,063	sw.	23	w.	26	3	17	11	6.5	.....	.....
Hatteras	11	12	50	30.05	30.06	+ .06	79.0	+ 0.8	87	22	84	65	1	74	17	75	73	86	2.66	− 3.2	14	7,762	sw.	46	nw.	25	10	15	6	5.0	.....	.....
Manteo	12	12	46	.....	.....	.....	78.2	.....	92	24	86	60	1	71	.....	.....	.....	.....	.....	5.12	.....	11	.....	sw.	.....	.....	.....	18	7	6	.....	.....	.....
Raleigh	376	103	110	29.65	30.04	+ .03	78.2	+ 1.4	94	24	87	62	1	70	24	70	68	81	3.48	− 2.4	11	4,508	sw.	29	w.	11	5	15	11	6.2	.....	.....
Wilmington	78	81	91	29.99	30.07	+ .07	79.0	+ 1.4	92	26	86	65	1	72	21	74	72	86	7.67	+ 1.2	20	4,383	sw.	24	w.	5	2	24	5	6.1	.....	.....
Charleston	48	11	92	30.03	30.08	+ .07	81.3	+ 1.0	95	27	88	71	5	75	17	75	73	80	4.43	− 2.5	12	5,739	s.	26	nw.	2	4	13	14	6.6	.....	.....
Columbia, S. C	351	41	57	29.69	30.06	+ .05	79.4	− 0.1	94	26	88	67	1	71	22	72	70	84	3.44	− 3.3	13	4,443	s.	28	sw.	29	3	18	10	6.4	.....	.....
Augusta	180	89	97	29.88	30.07	+ .06	79.7	+ 0.8	94	27	88	68	14	71	24	73	71	83	4.93	− 0.6	14	3,617	s.	40	sw.	2	0	15	16	6.9	.....	.....
Savannah	65	150	194	30.01	30.08	+ .07	81.0	+ 1.6	94	26	89	69	21	73	24	74	72	83	4.91	− 2.6	19	6,433	sw.	39	sw.	29	1	18	12	7.1	.....	.....
Jacksonville	43	96	129	30.04	30.09	+ .08	82.0	+ 1.9	95	14	90	68	17	74	26	74	72	81	8.47	+ 2.3	16	5,381	s.	50	sw.	14	9	16	6	5.1	.....	.....
Florida Peninsula.							82.7	+ 0.7											74	3.57	− 3.4									4.8		
Key West	22	10	64	30.02	30.04	+ .06	84.2	+ 0.4	91	4	90	72	11	79	17	76	73	71	1.29	− 3.4	14	7,422	se.	22	se.	25	15	16	0	3.8	.....	.....
Miami	25	37	72	30.04	30.07	.....	81.6	− 0.4	89	4	86	71	8	77	15	76	74	74	3.77	− 3.8	17	6,594	e.	27	se.	8	2	21	8	6.2	.....	.....
Sand Key	23	39	72	29.99	30.02	+ .04	82.2	.....	88	4	85	70	11	80	15	76	74	73	1.10	.....	10	10,462	e.	34	se.	13	20	11	0	3.4	.....	.....
Tampa	35	79	96	30.04	30.07	+ .07	82.2	+ 2.2	94	25	91	70	11	74	22	74	72	80	5.64	− 3.0	17	4,084	ne.	33	se.	13	4	21	6	5.6	.....	.....
Titusville	44	6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
East Gulf States.							79.4	+ 0.2											84	5.98	+ 1.1									6.2		
Atlanta	1,174	190	216	28.87	30.09	+ .08	76.8	+ 0.7	91	22	85	64	6	68	22	69	67	80	5.04	+ 0.6	12	5,433	w.	35	nw.	14	4	10	17	6.5	.....	.....
Macon	370	78	87	29.67	30.06	+ .05	79.2	+ 1.0	94	13	88	67	31	71	24	72	71	84	4.19	0.0	16	3,268	s.	30	s.	9	5	14	12	6.7	.....	.....
Thomasville	273	8	57	29.78	30.07	+ .07	81.0	0.0	95	13	91	68	16	71	25	73	72	87	3.96	− 1.1	15	2,678	sw.	23	nw.	15	7	13	11	5.8	.....	.....
Pensacola	56	140	182	30.00	30.06	+ .08	80.4	− 0.6	89	31	86	71	4	75	16	75	73	81	8.23	+ 1.1	16	6,480	s.	36	se.	8	5	11	15	6.6	.....	.....
Anniston	741	9	57	29.30	30.08	+ .09	77.2	+ 0.8	92	19	86	63	31	68	26	.....	.....	.....	.....	3.68	− 0.8	14	2,619	s.	20	sw.	28	6	20	5	5.7	.....	.....
Birmingham	700	11	48	29.32	30.08	+ .09	78.0	− 1.8	91	19	87	65	4	69	21	71	70	84	6.38	+ 1.9	14	3,351	s.	25	s.	28	8	16	7	5.5	.....	.....
Mobile	57	125	161	30.00	30.06	+ .08	80.6	+ 0.9	92	31	87	70	19	74	19	74	73	82	9.78	+ 3.0	16	4,837	sw.	34	nw.	15	9	13	9	5.5	.....	.....
Montgomery	223	100	112	29.82	30.06	+ .07	79.8	+ 0.1	92	19	88	68	6	71	22	72	71	84	5.35	+ 1.1	14	3,653	s.	27	w.	28	4	19	8	5.9	.....	.....
Meridian	375	85	93	29.66	30.04	+ .06	79.4	+ 0.9	92	11	88	68	5	70	22	72	71	84	5.60	+ 2.0	17	2,800	sw.	28	se.	19	1	16	14	7.2	.....	.....
Vicksburg	247	62	74	29.78	30.05	+ .07	79.4	− 0.2	92	5	87	69	19	72	20	73	72	88	5.13	+ 1.6	15	3,763	s.	28	w.	27	5	15	11	6.3	.....	.....
New Orleans	51	90	121	29.99	30.04	+ .06	81.8	+ 0.8	93	2	89	68	16	74	22	75	74	84	8.47	+ 2.9	22	3,726	se.	36	s.	10	1	22	8	6.6	.....	.....
West Gulf States.							80.6	− 0.4											80	5.94	+ 3.0									6.1		
Shreveport	249	77	93	29.75	30.01	+ .04	80.5	− 0.9	94	12	89	69	15	72	22	73	71	83	4.00	+ 1.8	16	4,416	s.	30	s.	11	3	8	20	7.1	.....	.....
Bentonville	1,303	11	44	28.65	29.98	+ .01	76.4	− 0.1	93	6	86	58	29	67	27	.....	.....	.....	.....	4.20	+ 0.2	9	3,255	s.	20	nw.	19	15	10	6	4.4	.....	.....
Fort Smith	457	79	94	29.50	29.97	.00	79.4	0.0	98	21	80	62	29	70	27	71	68	76	5.21	+ 1.6	15	4,452	e.	41	w.	10	7	9	15	6.1	.....	.....
Little Rock	357	139	147	29.64	30.01	+ .03	78.2	− 1.0	92	6	86	65	29	71	21	72	69	80	4.77	+ 1.1	11	5,063	s.	25	s.	9	6	9	16	6.8	.....	.....
Brownsville	57	3	40	.....	.....	.....	85.1	.....	97	31	94	72	16	76	23	.....	.....	.....	.....	0.68	.....	3	.....	se.	.....	.....	.....	.....	.....	.....	.....	.....	.....
Corpus Christi	20	69	77	29.95	29.97	+ .04	83.0	+ 0.9	95	4	88	74	9	79	18	78	77	86	2.96	+ 0.7	8	11,803	se.	38	se.	10	7	18	6	5.2	.....	.....
Dallas	512	109	117	29.44	29.98	.....	80.8	.....	101	1	89	66	28	73	21	.....	.....	.....	.....	6.30	.....	16	6,209	se.	38	nw.	28	3	15	13	7.0	.....	.....
Fort Worth	670	106	114	29.24	29.94	.00	80.0	− 2.9	100	1	88	65	28	72	26	73	70	78	9.02	+ 7.2	14	6,438	s.	34	w.	25	5	10	16	6.7	.....	.....
Galveston	54	106	114	29.96	30.02	+ .06	82.2	− 0.4	88	25	86	69	8	78	16	76	74	76	8.17	+ 3.2	14	7,873	s.	31	s.	8	17	9	5	4.5	.....	.....
Houston	138	111	121	29.85	29.99	.....	82.2	− 0.7	97	3	90	69	7	74	24	.....	.....	.....	.....	9.24	.....	18	5,006	se.	36	se.	5	1	18	12	6.7	.....	.....
Palestine	510	64	72	29.46	29.98	+ .01	80.8	+ 0.3	95	2	89	67	28	73	24	74	72	82	4.09	+ 1.9	12	4,928	s.	30	se.	21	3	11	17	7.1	.....	.....
San Antonio	701	80	91	29.24	29.96	+ .03	82.6	+ 0.6	102	4	92	68	7	74	31	74	71	77	7.80	+ 5.1	9	5,683	sw.	32	ne.	4	3	24	4	5.2	.....	.....
Taylor	582	55	63	29.39	30.00	+ .05	81.3	− 0.4	99	4	90	67	14	73	24	.....	.....	.....	.....	9.13	+ 6.7	13	5,877	s.	33	ne.	21	2	21	8	6.4	.....	.....

TABLE I.—*Climatological data for United States Weather Bureau stations, August, 1914*—Continued.

Districts and stations.	Elevation of instruments.			Pressure in inches.			Temperature of the air, in degrees Fahrenheit.										Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation, inches.			Wind.				Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Barometer above sea level, feet.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max. + mean min. ÷ 2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.					Total.	Departure from normal.	Days with 0.01 or more.	Total movement, miles.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.						
Ohio Valley and Tennessee.							**75.5**	**+ 0.7**											**73**	**5.19**	**+ 1.8**								**5.5**		
Chattanooga	762	189	213	29.27	30.07	+ .07	76.9	+ 0.4	94	19	86	61	17	68	28		69	67	78	2.84	− 0.9	16	4,350	w.	36	nw.	2	6	14	11	5.9	.....	.....
Knoxville	996	93	100	29.02	30.05	+ .04	76.3	+ 1.6	92	20	86	59	1	67	28		69	67	80	5.69	+ 1.8	13	2,774	sw.	19	n.	2	9	7	15	6.0	.....	.....
Memphis	399	76	97	29.62	30.04	+ .06	78.7	− 0.5	93	6	86	66	29	72	21		73	71	81	7.31	+ 4.1	12	4,982	sw.	42	sw.	28	9	7	15	6.0	.....	.....
Nashville	546	168	191	29.47	30.05	+ .05	77.6	− 0.2	92	2	86	60	30	69	26		70	67	77	8.64	+ 5.2	13	4,509	se.	37	sw.	25	9	8	14	5.9	.....	.....
Lexington	989	75	102	28.98	30.03	+ .02	74.8	+ 0.2	91	19	84	60	30	66	28		.....	.....	.....	4.69	+ 1.1	12	5,541	s.	30	sw.	10	12	10	9	5.0	.....	.....
Louisville	525	219	255	29.46	30.03	+ .03	77.3	+ 0.8	95	6	86	62	16	68	27		68	64	70	6.97	+ 3.5	14	6,767	s.	40	nw.	24	9	8	14	5.9	.....	.....
Evansville	431	72	82	29.55	30.01	+ .02	78.0	+ 1.0	96	6	87	63	29	70	27		69	65	70	3.59	+ 0.4	11	4,695	s.	28	sw.	28	8	10	13	5.8	.....	.....
Indianapolis	822	154	164	29.14	30.02	+ .02	74.6	+ 1.0	94	7	84	57	29	66	27		65	61	68	5.58	+ 2.2	15	6,126	sw.	32	sw.	10	8	15	8	5.3	.....	.....
Terre Haute	575	96	129	29.38	29.99	.....	76.4	.....	96	7	86	59	29	66	27		66	62	69	6.71	.....	12	5,860	s.	32	w.	19	6	16	9	5.9	.....	.....
Cincinnati	628	152	160	29.35	30.01	.00	76.7	+ 1.2	95	19	86	61	16	68	30		67	62	66	4.28	+ 1.0	12	3,711	sw.	23	se.	7	10	9	12	5.6	.....	.....
Columbus	824	173	222	29.16	30.02	+ .01	74.0	+ 1.0	96	19	84	57	4	64	29		65	61	69	4.78	+ 1.6	10	6,464	sw.	27	sw.	10	14	10	7	4.2	.....	.....
Dayton	899	181	216	29.06	29.99	.....	73.8	+ 0.2	93	23	84	57	26	64	32		65	60	68	3.74	+ 0.7	9	6,406	sw.	34	nw.	7	12	12	7	4.9	.....	.....
Pittsburgh	842	353	410	29.13	30.01	.00	73.2	+ 0.7	93	8	82	56	13	64	28		64	59	65	4.52	+ 1.3	10	6,721	sw.	39	nw.	2	6	16	9	5.9	.....	.....
Elkins	1,940	41	50	28.05	30.05	+ .04	69.6	+ 1.2	90	20	82	47	1	57	35		62	61	85	4.96	+ 1.3	13	1,809	w.	13	w.	23	10	14	7	5.4	.....	.....
Parkersburg	638	77	84	29.39	30.04	+ .02	74.9	+ 1.6	97	20	86	57	16	64	35		66	62	72	5.05	+ 1.5	12	3,257	se.	20	nw.	29	11	10	10	5.4	.....	.....
Lower Lake Region.							**70.1**	**+ 0.4**											**72**	**4.66**	**+ 1.7**								**5.0**		
Buffalo	767	247	280	29.18	30.00	+ .01	68.8	0.0	95	9	76	50	25	62	27		63	59	76	4.95	+ 2.0	14	9,616	sw.	54	w.	10	9	15	7	5.4	.....	.....
Canton	448	10	61	29.52	29.99	.....	65.6	− 2.2	91	9	77	35	26	54	41		.....	.....	.....	4.23	+ 1.5	13	5,919	w.	34	sw.	23	14	12	5	3.8	.....	.....
Oswego	335	76	91	29.62	29.98	− .01	67.8	− 1.0	90	7	75	50	26	60	25		62	58	74	3.21	+ 0.5	11	5,431	s.	26	ne.	11	12	9	10	4.9	.....	.....
Rochester	523	97	113	29.45	30.01	+ .02	69.1	+ 0.8	92	7	78	49	4	60	30		61	57	70	5.83	+ 2.9	13	4,601	sw.	24	sw.	18	11	11	9	5.4	.....	.....
Syracuse	597	97	113	29.38	30.01	+ .02	68.4	− 0.2	91	9	77	48	26	60	29		63	59	75	5.23	+ 1.9	13	6,088	s.	34	s.	14	11	9	11	5.2	.....	.....
Erie	714	92	102	29.24	29.99	− .02	70.1	+ 0.2	90	23	77	53	26	63	25		64	60	71	5.98	+ 2.7	15	6,303	s.	28	nw.	23	6	17	8	5.5	.....	.....
Cleveland	762	190	201	29.20	30.01	.00	71.8	+ 1.4	93	23	79	56	26	65	29		63	59	68	3.93	+ 0.8	10	7,920	se.	45	w.	23	8	14	9	5.3	.....	.....
Sandusky	629	62	103	29.33	30.00	− .01	72.9	+ 1.4	96	23	81	58	15	65	31		65	61	71	4.73	+ 1.4	12	7,569	sw.	52	nw.	23	7	16	8	5.7	.....	.....
Toledo	628	208	246	29.34	30.01	+ .01	72.2	+ 1.3	94	23	82	50	25	63	30		64	61	73	4.69	+ 2.0	10	9,331	sw.	55	nw.	23	15	13	3	3.8	.....	.....
Fort Wayne	856	113	124	29.10	30.01	.....	72.5	+ 1.4	95	19	83	52	26	62	29		64	59	69	2.62	.....	10	6,162	sw.	37	sw.	10	9	16	6	4.8	.....	.....
Detroit	730	218	245	29.23	30.01	.00	71.4	+ 1.5	91	23	81	49	25	62	25		63	59	72	3.84	+ 1.1	12	7,429	sw.	46	nw.	13	11	14	6	4.9	.....	.....
Upper Lake Region.							**66.7**	**+ 0.4**											**76**	**3.77**	**+ 0.8**								**5.1**		
Alpena	609	13	92	29.34	30.00	.00	64.6	+ 0.8	87	9	73	43	25	56	27		60	57	80	2.71	− 0.6	12	6,874	se.	49	se.	9	4	24	3	5.3	.....	.....
Escanaba	612	54	60	29.32	30.00	+ .01	63.4	− 1.1	84	6	71	43	24	56	26		59	57	80	4.17	+ 0.6	19	6,085	s.	39	ne.	10	7	14	10	5.8	.....	.....
Grand Haven	632	54	92	29.31	29.98	− .01	68.0	+ 0.2	91	8	76	49	25	60	32		62	59	75	3.73	+ 1.2	10	6,851	s.	32	s.	22	15	14	2	3.7	.....	.....
Grand Rapids	707	70	87	29.24	29.99	− .01	71.0	+ 1.0	93	9	81	48	25	61	30		63	59	71	3.49	+ 0.9	10	3,777	w.	20	w.	23	9	14	8	4.6	.....	.....
Houghton	684	62	72	29.24	29.96	− .01	62.8	− 0.5	90	9	72	42	24	54	27		.....	.....	.....	4.93	+ 2.1	14	5,161	se.	33	nw.	6	9	15	7	5.2	.....	.....
Lansing	878	11	62	29.07	30.00	.....	68.9	+ 0.3	93	8	81	41	25	57	35		62	59	79	3.33	+ 0.7	12	3,222	sw.	20	e.	9	12	9	10	4.9	.....	.....
Ludington	637	60	66	29.29	29.98	.....	66.2	.....	86	8	74	45	25	59	26		61	58	76	2.64	.....	8	6,807	s.	35	s.	23	12	12	7	4.7	.....	.....
Marquette	734	77	111	29.20	30.00	+ .02	63.0	− 0.5	94	9	71	42	28	55	28		57	54	73	2.12	− 0.7	14	6,208	w.	37	s.	8	10	9	12	6.2	.....	.....
Port Huron	638	70	120	29.31	30.00	.00	68.4	+ 1.1	90	6	77	47	4	60	32		62	59	77	4.21	+ 1.6	12	6,774	ne.	27	nw.	21	11	19	1	4.2	.....	.....
Saginaw	641	48	82	29.31	30.00	.....	68.7	.....	91	8	80	45	25	58	30		63	60	77	7.15	+ 4.3	11	5,333	s.	34	nw.	18	10	14	7	4.9	.....	.....
Sault Ste. Marie	614	11	61	29.31	30.00	+ .01	62.7	+ 2.1	93	9	72	42	24	53	29		57	55	80	2.40	− 0.7	11	5,052	e.	25	nw.	21	6	12	13	6.4	.....	.....
Chicago	823	140	310	29.13	30.00	.00	74.2	+ 3.0	96	18	81	61	14	68	24		66	62	69	3.76	+ 0.9	10	8,301	ne.	34	sw.	16	14	13	4	4.0	.....	.....
Green Bay	617	109	144	29.31	29.96	− .03	67.6	+ 0.6	93	8	77	46	24	58	26		61	57	74	5.26	+ 2.2	10	6,827	s.	36	sw.	23	5	11	15	6.5	.....	.....
Milwaukee	681	119	133	29.26	29.99	− .01	70.3	+ 1.6	89	9	78	53	27	63	26		63	59	72	1.34	− 1.5	10	6,706	ne.	49	sw.	16	11	17	3	4.7	.....	.....
Duluth	1,133	11	47	28.76	29.96	− .01	62.0	− 2.9	90	8	70	42	27	54	32		58	55	82	4.20	+ 0.7	11	8,641	ne.	35	w.	29	10	13	8	5.1	.....	.....
North Dakota.							**64.2**	**− 2.6**											**70**	**2.55**	**+ 0.8**								**5.0**		
Moorhead	918	10	208	28.96	29.96	.00	65.0	−0.9	93	15	77	39	26	53	35		58	55	76	2.89	− 0.2	12	4,860	se.	34	se.	7	18	8	5	3.5	.....	.....
Bismarck	1,674	8	57	28.23	29.99	+ .05	64.5	− 3.6	97	15	77	33	26	52	44		58	54	74	2.02	0.0	13	5,598	se.	37	w.	4	10	14	7	5.3	.....	.....
Devils Lake	1,482	11	44	28.38	29.94	.00	63.2	− 1.9	94	4	76	35	26	51	41		55	49	66	2.06	− 0.7	8	6,971	s.	38	w.	5	9	10	12	5.8	.....	.....
Williston	1,872	40	47	27.99	29.94	+ .01	64.1	− 3.8	99	3	78	33	26	51	47		54	48	63	3.22	+ 1.9	7	4,290	se.	34	se.	24	6	16	9	5.6	.....	.....
Upper Mississippi Valley.							**74.5**	**+ 1.6**											**67**	**3.66**	**+ 0.4**								**4.9**		
Minneapolis	918	10	208	28.97	29.94	.....	69.2	.....	96	8	79	47	26	60	30		.....	.....	.....	8.70	+ 5.0	10	7,388	ne.	45	nw.	22	8	10	13	5.6	.....	.....
St. Paul	837	201	236	29.05	29.95	− .02	68.8	− 0.7	95	8	79	47	26	59	32		.....	.....	.....	4.48	+ 1.0	13	7,715	nw.	44	nw.	9	9	13	9	5.7	.....	.....
La Crosse	714	11	48	29.21	29.96	− .02	70.9	+ 0.9	95	8	81	50	15	60	33		.....	.....	.....	2.92	− 0.5	10	3,092	se.	26	w.	22	10	9	12	5.5	.....	.....
Madison	974	70	78	28.96	29.99	.00	70.3	+ 0.7	93	8	80	52	24	61	28	62	51	67		3.60	+ 0.4	7	5,693	sw.	38	n.	18	11	12	8	5.3	.....	.....
Charles City	1,015	10	49	28.91	29.96	− .01	70.4	− 0.3	96	8	82	46	14	59	37	64	61	76		2.55	− 0.9	9	3,860	s.	27	ne.	16	9	19	3	4.7	.....	.....
Davenport	606	71	79	29.32	29.98	.00	75.0	+ 2.0	96	8	86	53	25	64	31	65	59	63		2.01	− 1.6	7	4,689	e.	22	nw.	23	11	15	5	4.5	.....	.....
Des Moines	861	84	97	29.05	29.93	− .04	75.9	+ 2.9	98	17	87	52	14	65	36	65	59	61		1.77	− 1.8	7	5,647	sw.	35	nw	31	10	16	5	4.6	.....	.....
Dubuque	698	81	96	29.25	29.99	+ .01	72.8	+ 0.8	96	8	83	49	29	63	32	64	59	66		4.01	+ 1.0	6	4,036	s.	31	nw.	16	8	13	10	5.3	.....	.....
Keokuk	614	64	78	29.32	29.98	.00	77.5	+ 2.9	97	18	88	59	28	67	31	66	61	62		2.61	− 0.6	8	4,898	ne.	25	s.	22	12	16	3	3.9	.....	.....
Cairo	356	87	93	29.61	29.98	− .01	78.6	+ 1.6	97	2	87	64	30	70	28	71	68	76		2.52	− 0.4	10	4,810	s.	38	n.	13	10	10	11	5.6	.....	.....
Peoria	609	11	45	29.34	30.00	+ .01	75.4	+ 2.9	98	23	88	53	4	63	39	65	61	69		2.40	− 0.5	7	4,052	s.	23	sw.	17	12	15	4	4.3	.....	.....
Springfield, Ill.	644	10	91	29.31	29.98	− .01	77.2	+ 3.2	97	18	88	58	4	66	32	66	62	65		3.32	+ 0.5	9	4,950	s.	30	nw.	13	11	13	7	5.0	.....	.....
Hannibal	534	74	109	29.42	29.98	.00	77.4	+ 2.4	97	18	89	56	15	66	35		.....	.....	.....	4.99	+ 1.6	11	5,843	sw.	31	w.	19	12	13	6	4.5	.....	.....
St. Louis	567	265	303	29.38	29.98	− .01	78.9	+ 1.7	98	6	88	63	29	70	25	68	62	64		5.42	+ 2.8	10	7,807	s.	42	s.	7	13	13	5	4.5	.....	.....
Missouri Valley.							**75.2**	**+ 1.4**											**65**	**2.75**	**− 0.6**								**4.2**		
Columbia, Mo.	781	11	84	29.16	29.97	.00	78.2	+ 3.5	97	8	89	60	15	67	33	.....	.....	.....	.....	7.35	+ 4.3	12	4,876	s.	27	w.	13	11	11	9	5.3	.....	.....
Kansas City	963	161	181	28.95	29.95	− .02	78.0	+ 2.2	98	7	87	58	28	69	26	67	62	64		3.12	− 1.6	7	7,457	s.	33	n.	28	17	10	4	3.6	.....	.....
St. Joseph	967	11	49	28.94	29.94	.....	79.0	.....	99	7	90	58	28	68	30	66	61	62		2.25	.....	7	5,133	ne.	22	sw.	31	15	14	2	3.7	.....	.....
Springfield, Mo.	1,324	98	104	28.61	29.99	+ .02	76.4	+ 1.6	92	6	85	60	28	68	24	68	64	74		4.70	+ 0.4	10	5,929	s.	37	nw..	19	11	15	5	4.2	.....	.....
Iola	984	11	50	28.93	29.95	− .01	78.4	+ 2.1	99	7	90	58	11	66	34	.....	.....	.....	.....	2.74	− 0.7	7	4,440	s.	22	nw.	21	13	14	4	3.7	.....	.....
Topeka	983	85	101	.....	.....	.....	77.6	+ 1.6	98	7	89	60	28	67	31	.....	.....	.....	.....	2.04	− 2.2	9	6,537	s.	32	w.	21	15	15	1	3.5	.....	.....
Lincoln	1,189	11	84	28.69	29.92	− .03	76.6	+ 2.3	100	17	88	55	27	65	34	66	61	67		1.47	− 2.2	8	6,703	s.	41	nw.	9	15	15	1	3.7	.....	.....
Omaha	1,105	115	121	28.79	29.94	− .02	77.0	+ 2.6	100	17	88	55	26	66	29	65	60	64		2.24	− 1.4	9	5,254	n.	25	nw.	23	14	15	2	4.1	.....	.....
Valentine	2,598	47	54	27.28	29.95	+ .01	71.0	− 0.3	101	7	83	46	10	59	40	60	54	63		2.50	− 0.3	10	6,510	e.	40	w.	7	17	11	3	3.7	.....	.....
Sioux City	1,135	94	164	28.75	29.93	− .02	74.0	+ 1.4	100	17	85	50	28	63	31	60	60	68		1.74	− 1.3	11	7,851	s.	52	nw.	4	15	11	5	4.2	.....	.....
Huron	1,306	59	74	28.58	29.96	+ .01	69.2	+ 0.1	98	15	82	39	26	57	40	60	55	68		1.29	− 1.4	8	6,889	se.	38	s.	28	9	17	5	4.7	.....	.....
Pierre	1,572	70	75	28.32	29.96	+ .02	71.9	− 1.2	103	7	84	47	25	60	37	60	52	57		2.19	+ 0.2	8	6,487	se.	37	e.	17	14	10	7	4.5	.....	.....
Yankton	1,233	49	57	28.63	29.92	− .03	73.5	+ 0.7	101	17	85	48	26	62	41	.....	.....	.....	.....	1.58	− 1.5	12	4,629	e.	29	sw.	8	9	15	7	5.5	.....	.....

TABLE I.—*Climatological data for United States Weather Bureau stations, August, 1914*—Continued.

Districts and stations.	Elevation of instruments.			Pressure in inches.			Temperature of the air, in degrees Fahrenheit.									Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation, inches.			Wind.				Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Barometer above sea level, feet.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max. + mean min. ÷ 2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.				Total.	Departure from normal.	Days with 0.01 or more.	Total movement, miles.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.					
Northern Slope.							66.2	− 0.6										54	1.54	+ 0.3								4.3		
Havre	2,505	11	44	27.35	29.94	+ .03	64.4	− 2.5	99	3	78	35	25	50	44	54	47	61	2.43	+ 1.2	8	4,512	sw.	46	nw.	30	12	13	6	4.8	.....	.....
Helena	4,110	87	114	25.84	29.95	+ .01	65.6	− 0.5	95	2	80	39	19	52	39	51	39	45	0.21	− 0.5	3	6,312	s.	30	sw.	6	14	14	3	4.0	.....	.....
Kalispell	2,962	11	34	26.93	29.94	+ .01	63.1	+ 0.2	94	2	80	35	9	47	44	50	41	53	1.31	+ 0.4	2	3,071	w.	26	sw.	4	15	13	3	4.0	.....	.....
Miles City	2,371	26	48	27.47	29.96	+ .03	68.9	− 2.6	101	3	84	38	25	54	46	56	50	60	2.51	+ 1.5	9	3,634	n.	34	n.	17	13	14	4	4.2	.....	.....
Rapid City	3,259	50	58	26.62	29.97	+ .04	68.3	− 0.5	99	7	81	41	26	56	36	56	46	51	1.95	− 0.2	6	5,627	n.	39	w.	21	12	14	5	4.5	.....	.....
Cheyenne	6,088	84	101	24.11	29.95	+ .03	65.4	− 0.4	89	16	78	45	11	53	38	52	44	56	1.67	+ 0.2	12	7,753	nw.	40	sw.	16	4	19	8	5.8	.....	.....
Lander	5,372	60	68	24.71	29.95	+ .03	66.4	+ 0.7	94	6	83	39	29	50	44	51	39	46	0.15	− 0.4	3	4,286	sw.	38	sw.	6	14	14	3	4.0	.....	.....
Sheridan	3,790	10	47	26.14	29.98	.....	65.1	.....	97	7	82	38	27	48	49	52	43	56	0.65	.....	5	3,895	nw.	36	nw.	31	12	14	5	4.2	.....	.....
Yellowstone Park	6,200	11	48	23.97	29.96	+ .03	59.4	− 1.5	85	6	75	34	25	44	41	46	35	48	0.20	− 0.8	4	5,387	nw.	33	s.	27	17	13	1	3.4	.....	.....
North Platte	2,821	11	51	27.09	29.96	+ .02	74.0	+ 1.8	105	16	88	48	10	60	47	62	56	64	3.45	+ 1.0	12	4,597	s.	25	w.	18	17	11	3	3.9	.....	.....
Middle Slope.							76.4	+ 1.1										63	2.40	0.0								4.2		
Denver	5,291	129	172	24.81	29.97	+ .05	71.0	+ 0.6	96	16	84	51	26	57	37	56	48	56	2.43	+ 1.1	15	5,704	sw.	43	n.	1	12	17	2	4.2	.....	.....
Pueblo	4,685	80	86	25.35	29.95	+ .04	72.6	+ 0.5	98	17	88	50	30	58	41	57	50	57	2.18	+ 0.6	10	3,874	nw.	40	w.	26	17	11	3	3.8	.....	.....
Concordia	1,398	42	50	28.50	29.93	− .02	79.3	+ 2.8	102	17	92	58	11	67	32	66	60	60	2.11	− 0.7	5	4,796	s.	24	w.	9	9	19	3	4.8	.....	.....
Dodge	2,509	11	51	27.42	29.96	+ .03	77.1	+ 0.6	98	20	90	58	28	65	32	65	60	66	1.23	− 1.4	6	6,978	s.	35	nw.	4	16	13	2	3.5	.....	.....
Wichita	1,358	139	158	28.52	29.92	− .03	78.6	+ 1.1	98	20	89	60	28	68	28	67	62	65	3.68	+ 0.6	10	8,497	s.	36	se.	5	18	9	4	3.5	.....	.....
Oklahoma	1,214	10	47	28.70	29.94	.00	79.6	+ 1.1	101	2	90	62	29	69	27	70	66	73	2.76	− 0.4	7	8,130	s.	36	n.	27	7	18	6	5.5	.....	.....
Southern Slope.							78.3	− 0.8										63	5.93	+ 3.8								4.6		
Abilene	1,738	10	52	28.18	29.95	+ .03	78.0	− 3.2	97	2	86	66	16	70	25	70	68	77	15.70	+13.7	16	5,826	s.	24	nw.	23	8	9	14	6.1	.....	.....
Amarillo	3,676	10	49	26.30	29.95	+ .03	75.6	+ 1.0	94	31	88	57	28	63	33	64	60	68	2.97	+ 0.2	7	6,559	s.	31	sw.	31	19	11	1	3.5	.....	.....
Del Rio	944	64	71	28.94	29.90	.00	82.8	− 1.2	99	1	92	67	14	74	24	.....	.....	.....	3.71	+ 1.2	6	6,601	e.	42	ne.	6	9	20	2	4.7	.....	.....
Roswell	3,566	75	85	26.39	29.92	+ .04	76.8	+ 0.2	97	1	90	58	15	64	34	63	57	58	1.33	− 0.1	7	4,964	s.	40	ne.	5	12	17	2	4.0	.....	.....
Southern Plateau.							77.4	0.0										47	0.93	− 0.2								2.7		
El Paso	3,762	110	133	26.19	29.86	+ .02	78.5	− 0.1	98	17	90	63	15	67	33	63	56	56	1.85	+ 0.1	11	6,597	e.	55	ne.	10	14	16	3	3.8	.....	.....
Santa Fe	7,013	57	62	23.38	29.91	+ .02	66.8	− 0.2	86	17	78	49	27	56	29	53	46	55	2.51	+ 0.2	13	4,885	n.	30	s.	21	10	18	1	4.6	.....	.....
Flagstaff	6,908	8	57	.....	.....	.....	63.1	+ 0.3	85	16	78	39	31	48	40	.....	.....	.....	2.30	.....	9	.....	nw.	32	w.	28	10	19	3	.....	.....	.....
Phoenix	1,108	76	81	28.68	29.79	.00	89.2	+ 0.2	110	3	102	69	31	77	30	68	57	38	0.30	− 0.7	2	3,853	w.	30	s.	21	22	6	2	2.7	.....	.....
Yuma	141	9	58	29.63	29.77	+ .01	91.1	+ 1.0	115	3	106	67	31	76	38	73	64	48	0.00	− 0.4	0	4,584	s.	34	s.	13	31	0	0	0.3	.....	.....
Independence	3,910	11	42	25.96	29.87	+ .06	78.5	− 0.9	100	5	92	50	21	59	39	58	45	39	T.	− 0.1	0	3,928	w.	24	se.	12	27	4	0	2.0	.....	.....
Middle Plateau.							72.4	+ 0.8										34	0.50	− 0.2								2.5		
Reno	4,532	74	81	25.50	29.90	+ .06	71.2	+ 4.2	98	5	90	42	20	53	47	52	37	36	0.38	+ 0.1	1	4,888	w.	37	sw.	16	29	1	1	1.2	.....	.....
Tonopah	6,090	12	20	24.13	29.91	.....	73.4	.....	94	5	85	52	28	62	30	52	32	26	0.02	− 0.4	2	4,772	w.	31	e.	6	16	15	0	3.1	.....	.....
Winnemucca	4,344	18	56	25.62	29.93	+ .05	70.6	− 0.2	100	13	90	40	21	51	48	49	32	29	T.	− 0.2	0	3,877	sw.	24	sw.	15	28	3	0	1.0	.....	.....
Modena	5,479	10	43	24.67	29.89	+ .03	69.8	+ 1.2	93	15	86	41	29	53	39	51	35	34	0.73	− 1.1	4	7,962	sw.	50	sw.	16	18	12	1	2.9	.....	.....
Salt Lake City	4,360	147	189	25.62	29.88	− .03	75.6	+ 0.1	97	14	87	56	28	64	33	57	45	35	0.24	− 0.5	3	5,492	se.	34	e.	4	21	7	3	3.1	.....	.....
Durango	6,546	18	56	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Grand Junction	4,602	82	96	25.41	29.93	+ .03	74.7	− 1.4	96	16	88	51	27	62	32	57	45	42	1.74	+ 0.7	9	6,829	se.	34	se.	20	20	9	2	3.5	.....	.....
Northern Plateau.							71.5	+ 1.2										34	0.02	− 0.4								2.6		
Baker	3,471	48	53	26.47	30.00	+ .05	66.4	+ 1.5	96	14	83	39	17	50	42	50	35	36	0.01	− 0.4	1	4,453	nw.	18	n.	16	26	5	0	1.7	.....	.....
Boise	2,739	78	86	27.12	29.92	− .01	72.8	+ 1.0	101	14	88	48	18	57	39	54	37	32	0.04	− 0.1	1	3,436	nw.	26	w.	3	24	5	2	2.2	.....	.....
Lewiston	757	40	48	29.14	29.93	− .02	74.6	+ 1.1	105	14	91	48	24	58	47	.....	.....	.....	T.	− 0.4	0	2,408	w.	31	nw.	16	16	12	3	3.0	.....	.....
Pocatello	4,477	46	54	25.49	29.91	− .01	69.9	− 0.6	94	13	86	42	18	54	41	51	34	34	0.06	− 0.5	2	5,443	se.	32	sw.	17	20	10	1	2.8	.....	.....
Spokane	1,929	101	110	27.94	29.94	− .01	70.0	+ 3.1	100	2	85	44	31	55	41	52	37	36	0.01	− 0.5	1	4,232	sw.	24	sw.	15	17	9	5	3.2	.....	.....
Walla Walla	1,000	57	65	28.89	29.94	− .02	75.2	+ 1.4	101	13	88	53	24	62	38	56	38	30	T.	− 0.4	0	3,283	s.	20	w.	16	22	8	1	2.6	.....	.....
North Pacific Coast Region.							60.8	− 0.2										75	0.20	− 0.6								4.3		
North Head	211	11	56	29.88	30.11	+ .08	55.2	− 2.7	65	18	58	50	10	53	11	54	52	92	0.21	− 0.4	5	10,688	nw.	40	nw.	29	7	8	16	6.6	.....	.....
Port Crescent	259	8	53	29.83	30.11	+ .09	54.2	− 2.0	76	12	62	38	31	46	36	.....	.....	.....	0.11	− 0.6	3	3,338	nw.	14	nw.	7	9	18	4	4.6	.....	.....
Seattle	125	215	250	29.95	30.08	+ .08	63.2	+ 0.1	88	13	72	48	31	54	29	57	53	73	0.01	− 0.5	1	4,670	n.	24	s.	6	12	11	8	4.8	.....	.....
Tacoma	213	113	120	29.85	30.07	+ .05	62.8	− 0.2	89	13	73	47	9	52	33	56	51	68	T.	− 0.7	0	3,474	n.	21	sw.	6	15	12	4	4.0	.....	.....
Tatoosh Island	109	7	57	29.99	30.09	+ .09	53.9	− 1.4	67	12	58	46	24	50	19	53	52	96	1.09	− 1.0	5	7,466	s.	36	s.	13	10	8	13	5.8	.....	.....
Portland, Oreg.	153	68	106	29.85	30.03	+ .02	68.0	+ 2.1	93	12	79	49	31	57	33	59	54	64	0.01	− 0.6	1	4,325	nw.	19	n.	16	19	10	2	2.7	.....	.....
Roseburg	510	9	57	29.48	30.02	+ .02	68.6	+ 2.4	101	12	84	46	17	53	45	56	48	57	T.	− 0.3	0	2,522	n.	16	n.	8	22	7	2	1.9	.....	.....
Middle Pacific Coast Region.							64.6	− 0.3										62	0.00	0.0								3.5		
Eureka	62	73	89	29.97	30.04	+ .04	54.6	− 1.2	62	6	58	48	17	51	12	52	51	90	T.	− 0.1	0	4,111	nw.	22	n.	6	2	7	22	8.0	.....	.....
Mount Tamalpais	2,375	11	18	27.53	29.96	+ .03	68.6	+ 2.7	91	1	76	45	31	61	31	54	40	39	0.00	0.0	0	9,154	nw.	48	nw.	28	29	2	0	0.7	.....	.....
Point Reyes Light	490	7	18	29.44	29.96	.....	53.6	− 0.9	66	1	57	48	2	50	17	.....	.....	.....	0.00	0.0	0	14,208	nw.	48	nw.	28	6	3	22	7.6	.....	.....
Red Bluff	332	50	56	29.52	29.86	.00	79.7	− 1.3	105	4	96	52	31	63	43	61	46	37	0.00	0.0	0	2,860	s.	17	n.	17	31	0	0	0.3	.....	.....
Sacramento	69	106	117	29.81	29.88	+ .03	71.2	− 0.9	99	5	87	48	20	56	39	60	35	60	0.00	0.0	0	6,656	s.	22	s.	30	31	0	0	0.1	.....	.....
San Francisco	155	200	204	29.79	29.96	+ .04	58.2	+ 0.2	83	1	63	51	23	53	30	54	52	86	0.00	0.0	0	8,646	w.	33	w.	4	9	12	10	5.2	.....	.....
San Jose	141	12	110	29.82	29.97	.....	66.2	− 0.5	94	1	79	48	20	54	42	.....	.....	.....	0.00	0.0	0	4,262	nw.	19	se.	18	27	4	0	2.3	.....	.....
South Pacific Coast Region.							69.8	− 0.7										66	0.00	0.0								2.8		
Fresno	327	89	98	29.52	29.86	+ .04	80.3	− 0.9	106	5	97	54	31	64	39	60	44	35	T.	0.0	0	5,793	nw.	21	nw.	8	30	1	0	0.4	.....	.....
Los Angeles	338	159	191	29.58	29.94	+ .06	68.2	− 0.4	88	16	78	56	9	59	26	61	57	76	0.00	0.0	0	3,777	sw.	15	s.	8	17	14	0	3.1	.....	.....
San Diego	87	62	70	29.85	29.94	+ .05	66.2	− 2.5	78	16	70	60	5	62	14	61	59	80	0.00	0.0	0	4,943	nw.	21	nw.	1	20	7	4	3.6	.....	.....
San Luis Obispo	201	47	54	29.77	29.99	+ .05	64.5	+ 1.0	91	16	75	50	21	54	36	56	52	75	T.	0.0	0	2,310	nw.	12	w.	3	12	17	2	4.1	.....	.....
West Indies.																																
San Juan	82	8	54	29.95	30.03	+ .06	79.6	.....	87	19	84	72	15	75	14	.....	.....	.....	4.71	− 2.7	26	10,312	ne.	38	ne.	30	11	19	1	3.9	.....	.....
Panama.																																
Ancon	92	6	69	29.71	29.80	.....	81.8	.....	94	3	90	70	28	74	21	76	75	90	6.09	− 1.4	24	5,555	nw.	35	ne.	7	0	9	22	8.2	.....	.....
Culebra	404	5	62	29.42	29.83	.....	80.4	.....	91	30	87	69	28	74	20	75	75	94	9.73	− 0.8	22	5,694	nw.	31	ne.	28	0	5	26	8.6	.....	.....
Colon	10	5	71	29.83	29.84	.....	81.0	.....	88	5	84	74	12	78	11	78	77	88	16.01	+ 0.9	25	7,983	n.	28	w.	23	2	10	19	7.7	.....	.....

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during August, 1914, at all stations furnished with self-registering gages.*

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.												
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Abilene, Tex.	10	6.48 a. m.	10.50 a. m.	2.25	7.02 a. m.	7.52 a. m.	0.01	0.16	0.33	0.46	0.68	0.98	1.19	1.35	1.45	1.55	1.62	.....	.....	.....	.....
	11	D. N. a. m.	9.00 a. m.	2.05	5.49 a. m.	6.39 a. m.	.08	.09	.25	.43	.67	.95	1.22	1.36	1.47	1.54	1.61	.....	.....	.....	.....
	13	D. N. a. m.	12 noon.	3.67	4.26 a. m.	5.01 a. m.	.18	.08	.13	.22	.38	.50	.63	.77	.....	.....	.....	.....	.....	.....	.....
					9.03 a. m.	9.53 a. m.	2.10	.12	.23	.29	.43	.70	.86	.96	1.08	1.17	1.24	.....	.....	.....	.....
	24	6.00 a. m.	10.11 a. m.	1.64	7.01 a. m.	7.24 a. m.	.41	.13	.32	.46	.65	.72	.....	.....	.....	.....	.....	.....	.....	.....	.....
	26	3.10 a. m.	9.00 a. m.	2.02	4.05 a. m.	4.48 a. m.	.49	.18	.35	.38	.45	.58	.66	.66	.81	.90	.....	.....	.....	.....	.....
Albany, N. Y.	11	1.42 p. m.	3.02 p. m.	1.85	1.54 p. m.	2.49 p. m.	.02	.05	.31	.68	1.05	1.40	1.58	1.60	1.66	1.67	1.67	1.82	.....	.....	.....
	19–20	11.40 p. m.	D. N. a. m.	0.68	12.05 a. m.	12.27 a. m.	.01	.21	.42	.53	.61	.65	.....	.....	.....	.....	.....	.....	.....	.....	.....
	21	11.20 a. m.	1.40 p. m.	0.77	11.38 a. m.	11.38 a. m.	.01	.57	.66	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Alpena, Mich.	10	.....	.....	0.71	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.41	.....	.....	.....
Amarillo, Tex.	9–10	10.25 p. m.	3.30 a. m.	0.74	9.19 p. m.	9.33 p. m.	.01	.13	.33	.53	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Anniston, Ala.	10	.....	.....	0.71	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.67	.....	.....	.....
Asheville, N. C.	11	4.45 p. m.	6.18 p. m.	0.69	5.17 p. m.	5.35 p. m.	.01	.23	.38	.56	.68	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	13	7.30 p. m.	9.45 p. m.	0.75	8.40 p. m.	9.08 p. m.	.10	.41	.62	.64	.64	.77	.85	.....	.....	.....	.....	.....	.....	.....	.....
	25	11.08 p. m.	11.45 p. m.	0.85	11.10 a. m.	11.37 a. m.	.01	.06	.24	.51	.66	.77	.83	.....	.....	.....	.....	.....	.....	.....	.....
		4.30 p. m.	5.00 p. m.	0.76	4.40 p. m.	4.48 p. m.	.05	.45	.71	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Atlanta, Ga.	20	9.37 a. m.	11.10 a. m.	3.26	9.54 a. m.	10.45 a. m.	.02	.50	.90	1.02	1.33	1.67	1.96	2.44	2.89	3.03	3.19	.....	.....	.....	.....
Atlantic City, N. J.	3	12 mid. a. m.	6.15 a. m.	1.00	4.25 a. m.	4.40 a. m.	.31	.37	.53	.60	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Augusta, Ga.	2	3.30 p. m.	7.05 p. m.	0.67	3.45 p. m.	4.10 p. m.	.01	.16	.23	.35	.46	.53	.....	.....	.....	.....	.....	.....	.....	.....	.....
Baker, Oreg.	3	.....	.....	0.01	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.01	.....	.....	.....
Baltimore, Md.	10	4.27 p. m.	5.10 p. m.	0.71	4.30 p. m.	4.46 p. m.	.01	.24	.55	.66	.69	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	24	4.40 p. m.	6.30 p. m.	0.87	4.28 p. m.	5.09 p. m.	.01	.08	.20	.43	.54	.58	.....	.....	.....	.....	.....	.....	.....	.....	.....
	29	3.45 p. m.	4.20 p. m.	0.79	3.51 p. m.	4.11 p. m.	.01	.27	.48	.66	.77	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Bentonville, Ark.	19–20	11.45 p. m.	3.30 a. m.	0.86	12.38 a. m.	1.08 a. m.	.02	.19	.40	.48	.51	.56	.66	.....	.....	.....	.....	.....	.....	.....	.....
	30	12.55 a. m.	5.10 a. m.	1.07	1.10 a. m.	1.56 a. m.	.04	.09	.14	.21	.24	.25	.35	.47	.51	.70	.75	.....	.....	.....	.....
Binghamton, N. Y.	20	4.20 p. m.	7.15 p. m.	0.72	4.33 p. m.	4.53 p. m.	.01	.07	.25	.45	.56	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Birmingham, Ala.	1	7.06 a. m.	8.25 a. m.	0.76	7.36 a. m.	8.02 a. m.	.14	.06	.21	.27	.39	.51	.55	.....	.....	.....	.....	.....	.....	.....	.....
	12	2.19 p. m.	5.32 p. m.	1.12	2.39 p. m.	3.34 p. m.	.07	.07	.10	.16	.30	.44	.56	.63	.64	.70	.87	.95	.....	.....	.....
Bismark, N. Dak.	2	.....	.....	0.44	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.28	.....	.....	.....
Block Island, R. I.	21	.....	.....	0.98	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.45	.....	.....	.....
Boise, Idaho.	3	.....	.....	0.04	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.04	.....	.....	.....
Boston, Mass.	20	.....	.....	1.30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.57	.....	.....	.....
Buffalo, N. Y.	29	.....	.....	1.11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.50	.....	.....	.....
Burlington, Vt.	11	12.03 p. m.	12.35 p. m.	0.66	12.09 p. m.	12.27 p. m.	.01	(*)	(*)	(*)	(*)	(*)	.65	.....	.....	.....	.....	.....	.....	.....	.....
Cairo, Ill.	10	.....	.....	0.93	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.45	.....	.....	.....
Canton, N. Y.	18	.....	.....	0.49	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.43	.....	.....	.....
Charles City, Iowa.	16	12.05 a. m.	1.40 a. m.	0.82	12.14 a. m.	12.49 a. m.	.04	.05	.13	.21	.30	.39	.47	.55	.....	.....	.....	.....	.....	.....	.....
	31	4.15 p. m.	5.18 p. m.	0.80	4.32 p. m.	5.07 p. m.	.02	.05	.13	.24	.40	.57	.68	.76	.....	.....	.....	.....	.....	.....	.....
Charleston, S. C.	4–5	.....	.....	1.73	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.55	.....	.....	.....
Charlotte, N. C.	26–27	.....	.....	0.79	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.40	.....	.....	.....
Chattanooga, Tenn.	2	4.23 p. m.	7.24 p. m.	0.83	4.31 p. m.	4.46 p. m.	.01	.24	.60	.72	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Cheyenne, Wyo.	25	6.25 p. m.	7.45 p. m.	0.75	6.31 p. m.	6.53 p. m.	.01	.07	.10	.37	.62	.68	.....	.....	.....	.....	.....	.....	.....	.....	.....
Chicago, Ill.	9	2.19 p. m.	3.50 p. m.	1.01	2.52 p. m.	3.11 p. m.	.09	.08	.35	.70	.91	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	13	11.35 a. m.	2.40 p. m.	0.82	11.41 a. m.	12.06 p. m.	.01	.08	.22	.41	.58	.68	.....	.....	.....	.....	.....	.....	.....	.....	.....
Cincinnati, Ohio.	28	12.15 a. m.	11.00 a. m.	1.37	4.24 a. m.	4.55 a. m.	.30	.12	.23	.29	.37	.48	.56	.59	.....	.....	.....	.....	.....	.....	.....
Cleveland, Ohio.	23	.....	.....	1.56	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.66	.....	.....	.....
Columbia, Mo.	9	12.40 p. m.	1.30 p. m.	0.59	12.46 p. m.	1.16 p. m.	.01	.07	.15	.23	.40	.51	.56	.....	.....	.....	.....	.....	.....	.....	.....
	19	6.00 p. m.	D. N. p. m.	1.75	6.05 p. m.	6.45 p. m.	.01	.17	.32	.68	1.06	1.37	1.56	1.64	1.70	.....	.....	.....	.....	.....	.....
	25	D. N. a. m.	10.00 a. m.	2.47	4.53 a. m.	6.23 a. m.	.21	.08	.12	.15	.18	.23	.27	.44	.64	.79	.91	1.13	1.91	2.11	.....
Columbia, S. C.	14	2.12 a. m.	D. N. a. m.	0.81	2.17 a. m.	2.38 a. m.	.01	.21	.33	.49	.58	.62	.....	.....	.....	.....	.....	.....	.....	.....	.....
Columbus, Ohio.	20	.....	.....	0.86	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.49	.....	.....	.....
Concord, N. H.	17	.....	.....	1.23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.96	.....	.....	.....
Concordia, Kans.	9	5.32 p. m.	8.17 p. m.	1.42	5.40 p. m.	6.06 p. m.	.01	.17	.48	.81	1.01	1.11	1.13	.....	.....	.....	.....	.....	.....	.....	.....
Corpus Christi, Tex.	9	4.20 a. m.	6.20 a. m.	0.98	5.04 a. m.	5.44 a. m.	.06	.16	.21	.34	.55	.60	.67	.75	.82	.....	.....	.....	.....	.....	.....
	16	9.21 a. m.	10.32 a. m.	0.70	9.21 a. m.	9.58 a. m.	.00	.09	.18	.24	.29	.31	.48	.59	.64	.....	.....	.....	.....	.....	.....
Davenport, Iowa.	5–6	10.44 p. m.	About 2.20 a. m.	0.67	1.51 a. m.	2.06 a. m.	.29	.12	.23	.35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Dayton, Ohio.	21	.....	.....	0.60	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.54	.....	.....	.....
Del Rio, Tex.	5–6	9.40 p. m.	12.30 a. m.	2.49	9.42 p. m.	11.02 p. m.	T	.19	.35	.41	.46	.57	.72	.78	.83	1.00	1.12	1.20	1.44	.....	.....
Denver, Colo.	1	4.18 p. m.	5.07 p. m.	1.09	4.21 p. m.	4.48 p. m.	.01	.34	.86	.95	.98	1.04	1.07	.....	.....	.....	.....	.....	.....	.....	.....
Des Moines, Iowa.	31	6.55 p. m.	D. N. p. m.	0.98	8.05 p. m.	8.25 p. m.	.09	.30	.55	.67	.73	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Detroit, Mich.	10	1.40 p. m.	4.20 p. m.	0.57	1.46 p. m.	2.07 p. m.	.01	.05	.11	.38	.47	.51	.....	.....	.....	.....	.....	.....	.....	.....	.....
Devils Lake, N. Dak.	22	.....	.....	0.68	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.29	.....	.....	.....
Dodge City, Kans.	19	.....	.....	0.58	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.55	.....	.....	.....
Dubuque, Iowa.	31–11	8.05 p. m.	D. N. a. m.	3.18	8.10 p. m.	9.00 p. m.	.01	.41	.72	1.03	1.23	1.25	1.30	1.38	1.51	1.57	1.63	.....	.....	.....	.....
					10.52 p. m.	11.36 p. m.	2.03	.19	.32	.36	.39	.43	.51	.60	.69	.74	.....	.....	.....	.....	.....
Duluth, Minn.	9	.....	.....	1.30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.56	.....	.....	.....
Durango, Colo.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Eastport, Me.	1	.....	.....	1.24	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.47	.....	.....	.....
Elkins, W. Va.	24	4.48 p. m.	7.36 p. m.	1.42	4.48 p. m.	5.11 p. m.	.00	.11	.30	.44	.54	.59	.....	.....	.....	.....	.....	.....	.....	.....	.....
					6.08 p. m.	6.29 p. m.	.83	.21	.35	.43	.51	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
El Paso, Tex.	19	.....	.....	0.60	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.57	.....	.....	.....
Erie, Pa.	18	10.27 p. m.	D. N. a. m.	1.16	11.05 p. m.	11.50 p. m.	.01	.08	.27	.41	.49	.52	.65	.83	.92	1.02	.....	.....	.....	.....	.....
	20	11.45 a. m.	12.25 p. m.	0.60	11.53 a. m.	12.08 p. m.	.01	.27	.50	.56	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Escanaba, Mich.	13	D. N. a. m.	6.40 a. m.	0.77	4.44 a. m.	4.55 a. m.	.03	.35	.58	.61	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	20	6.10 a. m.	6.42 a. m.	0.55	6.13 a. m.	6.26 a. m.	.01	.32	.41	.53	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Eureka, Cal.	25, 31	.....	.....	T	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	T	.....	.....	.....
Evansville, Ind.	25	.....	.....	0.87	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.48	.....	.....	.....
Flagstaff, Ariz.	29	.....	.....	0.98	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Fort Smith, Ark.	10	3.06 p. m.	8.06 p. m.	1.15	3.15 p. m.	3.40 p. m.	.01	.20	.44	.66	.83	.89	.....	.....	.....	.....	.....	.....	.....	.....	.....
Fort Wayne, Ind.	19	.....	.....	0.58	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.25	.....	.....	.....
Fort Worth, Tex.	5	2.15 p. m.	3.50 p. m.	1.48	2.47 p. m.	3.21 p. m.	.11	.09	.39	.93	.92	1.14	1.29	1.35	.....	.....	.....	.....	.....	.....	.....
	12–13	6.11 p. m.	4.22 a. m.	1.17	6.31 p. m.	6.58 p. m.	.11	.18	.30	.38	.46	.58	.66	.....	.....	.....	.....	.....	.....	.....	.....
	15	12.57 a. m.	8.35 a. m.	2.50	2.02 a. m.	2.37 a. m.	.37	.09	.13	.21	.35	.48	.65	.79	.....	.....	.....	.....	.....	.....	.....
					4.16 a. m.	4.48 a. m.	1.48	.06	.12	.17	.37	.49	.56	.61	.....	.....	.....	.....	.....	.....	.....
	25	5.22 p. m.	6.30 p. m.	0.58	5.32 p. m.	5.47 p. m.	.01	.18	.34	.54	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	28	12.11 a. m.	4.15 a. m.	1.05	1.25 a. m.	1.52 a. m.	.03	.09	.17	.31	.42	.50	.55	.....	.....	.....	.....	.....	.....	.....	.....
Fresno, Cal.	7	.....	.....	T	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	T	.....	.....	.....
Galveston, Tex.	6	6.30 a. m.	12.40 p. m.	1.59	7.53 a. m.	8.12 a. m.	.20	.38	.66	.84	.91	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	8	6.10 a. m.	3.40 p. m.	3.01	7.54 a. m.	9.05 a. m.	.22	.08	.23	.39	.64	.95	1.26	1.48	1.69	1.94	2.14	2.36	2.65	.....	.....
	22	8.10 a. m.	8.55 a. m.	0.80	8.14 a. m.	8.37 a. m.	.01	.16	.30	.51	.68	.75	.....	.....	.....	.....	.....	.....	.....	.....	.....
Grand Haven, Mich.	16	7.15 p. m.	D. N. p. m.	1.39	10.20 p. m.	11.08 p. m.	.14	.15	.32	.44	.57	.58	.60	.61	1.03	1.20	1.25	.....	.....	.....	.....
	30	D. N. a. m.	8.00 a. m.	0.79	5.27 a. m.	5.47 a. m.	.01	.28	.43	.50	.56	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Grand Junction, Colo.	22	5.20 p. m.	6.05 p. m.	0.59	5.23 p. m.	5.36 p. m.	.01	.24	.54	.58	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Grand Rapids, Mich.	16–17	8.00 p. m.	D. N. a. m.	1.33	10.30 p. m.	11.13 p. m.	.21	.09	.12	.24	.30	.38	.51	.68	.83	.89	.....	.....	.....	.....	.....
Green Bay, Wis.	17–18	9.00 p. m	D. N. a. m.	1.71	10.23 p. m.	11.26 p. m.	.24	.14	.15	.15	.24	.46	.60	.86	.98	1.05	1.11	1.25	1.30	.....	.....
Hannibal, Mo.	31	.....	.....	1.45	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.52	.....	.....
Harrisburg, Pa.	10	9.40 p. m.	10.30 p. m.	0.57	9.50 p. m.	10.15 p. m.	.02	.08	.20	.33	.47	.53	.....	.....	.....	.....	.....	.....	.....	.....	.....
	20	5.26 p. m.	9.00 p. m.	0.80	7.42 p. m.	8.22 p. m.	.66	.30	.61	.73	.77	.80	.84	.90	1.00	.....	.....	.....	.....	.....	.....
Hartford, Conn.	20	.....	.....	0.45	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.45	.....	.....	.....

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during August, 1914, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.													
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Hatteras, N. C.	13	2.10 a. m.	4.05 a. m.	0.71	2.46 a. m.	3.10 a. m.	.11	.10	.16	.26	.42	.53	.....	.....	.....	.....	.....	.....	.....	.....	.....
Havre, Mont.	18	.....	.....	0.60	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.43	.....	.....	.....
Helena, Mont.	18	.....	.....	0.12	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.07	.....	.....	.....
Houghton, Mich.	9	.....	.....	0.71	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.48	.....	.....	.....
Houston, Tex.	5	3.50 p. m.	6.10 p. m.	1.13	5.08 p. m.	5.36 p. m.	.09	.20	.48	.69	.83	.89	.93	.....	.....	.....	.....	.....	.....	.....	.....
	7	D. N. a. m.	11.00 a. m.	2.61	5.12 a. m.	5.59 a. m.	.20	.15	.34	.60	.84	.96	1.01	1.05	1.15	1.25	1.30	.....	.....	.....	.....
					6.35 a. m.	7.01 a. m.	1.65	.22	.27	.35	.52	.63	.67	.....	.....	.....	.....	.....	.....	.....	.....
	11	12.53 p. m.	2.40 p. m.	1.10	1.08 p. m.	1.43 p. m.	.04	.16	.33	.43	.64	.77	.81	.90	.....	.....	.....	.....	.....	.....	.....
Huron, S. Dak.	24	.....	.....	0.24	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.23	.....	.....	.....
Independence, Cal.	2,9	.....	.....	T.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	T.	.....	.....	.....
Indianapolis, Ind.	10	4.10 p. m.	5.38 p. m.	0.66	4.12 p. m.	4.24 p. m.	.01	.27	.56	.59	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	28–29	6.20 a. m.	D. N. a. m.	2.46	2.15 p. m.	2.55 p. m.	.86	.11	.26	.36	.40	.50	.59	.71	.76	.....	.....	.....	.....	.....	.....
					4.30 p. m.	4.59 p. m.	1.68	.27	.30	.34	.37	.41	.52	.....	.....	.....	.....	.....	.....	.....	.....
Iola, Kans.	24	.....	.....	0.66	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.54	.....	.....	.....
Jacksonville, Fla.	4	9.20 p. m.	11.25 p. m.	0.81	9.20 p. m.	9.35 p. m.	.00	.09	.41	.53	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	14	3.59 p. m.	6.20 p. m.	1.33	4.03 p. m.	4.52 p. m.	.01	.10	.21	.42	.74	.83	.85	.92	1.02	1.16	1.23	.....	.....	.....	.....
	17	4.47 p. m.	7.15 p. m.	1.40	4.57 p. m.	5.22 p. m.	.01	.17	.73	1.00	1.18	1.30	.....	.....	.....	.....	.....	.....	.....	.....	.....
	21	12.23 p. m.	1.20 p. m.	0.95	12.44 p. m.	12.58 p. m.	.01	.41	.70	.91	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Kalispell, Mont.	17	.....	.....	1.25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.39	.....	.....	.....
Kansas City, Mo.	21	3.27 p. m.	4.08 p. m.	0.57	3.49 p. m.	4.01 p. m.	.03	.19	.45	.54	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Keokuk, Iowa.	31	10.30 a. m.	1.00 p. m.	0.61	10.37 a. m.	11.06 a. m.	.04	.05	.14	.19	.33	.47	.50	.....	.....	.....	.....	.....	.....	.....	.....
Key West, Fla.	10	.....	.....	0.35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.24	.....	.....	.....
Knoxville, Tenn.	3	5.59 p. m.	D. N. p. m.	1.71	6.07 p. m.	6.41 p. m.	.01	.38	.85	1.06	1.19	1.33	1.42	1.47	.....	.....	.....	.....	.....	.....	.....
	13	7.35 a. m.	12.02 p. m.	0.96	9.14 a. m.	9.38 a. m.	.34	.05	.11	.35	.52	.56	.....	.....	.....	.....	.....	.....	.....	.....	.....
La Crosse, Wis.	9–10	.....	.....	0.94	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.69	.....	.....	.....
Lander, Wyo.	1	.....	.....	0.09	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.07	.....	.....	.....
Lansing, Mich.	10	.....	.....	0.69	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.53	.....	.....	.....
Lewiston, Idaho.	14	.....	.....	T.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	T.	.....	.....	.....
Lexington, Ky.	24	1.38 p. m.	4.10 p. m.	0.81	2.07 p. m.	2.28 p. m.	.21	.19	.37	.44	.50	.54	.....	.....	.....	.....	.....	.....	.....	.....	.....
Lincoln, Nebr.	9	.....	.....	0.55	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.52	.....	.....	.....
Little Rock, Ark.	25	8.58 p. m.	11.15 p. m.	1.67	9.03 p. m.	10.23 p. m.	.01	.08	.17	.24	.26	.30	.34	.40	.44	.56	.69	1.09	1.57	.....	.....
Los Angeles, Cal.	.....	.....	.....	(‡)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Louisville, Ky.	13	8.25 p. m.	9.50 p. m.	0.67	8.28 p. m.	8.47 p. m.	.02	.18	.37	.50	.56	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	20	12.02 p. m.	1.00 p. m.	0.68	12.12 p. m.	12.24 p. m.	.01	.12	.48	.57	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Ludington, Mich.	17–18	D. N. p. m.	5.55 a. m.	1.12	12.50 a. m.	1.04 a. m.	.04	.07	.37	.51	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Lynchburg, Va.	21	1.35 p. m.	2.30 p. m.	1.03	1.48 p. m.	2.14 p. m.	.01	.28	.45	.72	.90	.97	1.00	.....	.....	.....	.....	.....	.....	.....	.....
Macon, Ga.	4	.....	.....	0.75	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.63	.....	.....	.....
Madison, Wis.	18	5.10 p. m.	8.10 p. m.	0.99	5.26 p. m.	6.08 p. m.	.09	.09	.24	.37	.45	.51	.62	.66	.73	.76	.....	.....	.....	.....	.....
	31–Sept. 1	9.55 p. m.	D. N. a. m.	1.77	11.24 p. m.	12.03 a. m.	.36	.08	.21	.42	.62	.81	.92	.97	1.03	.....	.....	.....	.....	.....	.....
Marquette, Mich.	20	.....	.....	0.35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.21	.....	.....	.....
Memphis, Tenn.	20	1.05 p. m.	4.57 p. m.	0.96	1.05 p. m.	1.41 p. m.	.00	.06	.24	.37	.46	.51	.61	.83	.....	.....	.....	.....	.....	.....	.....
	26	8.05 a. m.	1.45 p. m.	1.14	12.11 p. m.	12.27 p. m.	.44	.12	.37	.60	.64	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Meridian, Miss.	3–4	D. N. p. m.	D. N. a. m.	1.66	11.11 p. m.	12.16 a. m.	.02	.07	.17	.18	.38	.44	.71	.89	1.00	1.10	1.16	1.32	1.50	.....	.....
Miami, Fla.	15	D. N. a. m.	D. N. a. m.	0.57	5.18 a. m.	5.31 a. m.	.04	.24	.46	.53	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Milwaukee, Wis.	30	.....	.....	0.32	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.24	.....	.....	.....
Minneapolis, Minn.	9	3.05 p. m.	8.20 p. m.	3.32	4.30 p. m.	5.20 p. m.	.37	.16	.30	.33	.39	.49	.59	.61	.64	.65	.71	.....	.....	.....	.....
					5.20 p. m.	6.10 p. m.	.....	.93	1.20	1.43	1.62	1.85	2.00	2.08	2.17	2.28	2.38	.....	.....	.....	.....
					6.10 p. m.	6.45 p. m.	.....	2.39	2.42	2.44	2.47	2.58	2.73	2.78	.....	.....	.....	.....	.....	.....	.....
	22	7.25 p. m.	10.40 p. m.	2.68	7.31 p. m.	8.10 p. m.	.01	.30	.57	.83	1.03	1.40	1.93	2.15	2.21	.....	.....	.....	.....	.....	.....
	31	3.16 p. m.	5.50 p. m.	1.30	3.20 p. m.	3.57 p. m.	.01	.07	.26	.41	.59	.70	.90	1.09	1.13	.....	.....	.....	.....	.....	.....
Mobile, Ala.	4	6.15 a. m.	9.05 a. m.	1.08	6.31 a. m.	6.55 a. m.	.01	.19	.49	.58	.75	.86	.....	.....	.....	.....	.....	.....	.....	.....	.....
	8	1.35 p. m.	4.35 a. m.	1.62	2.03 p. m.	2.33 p. m.	.01	.36	.70	.96	1.26	1.43	1.55	.....	.....	.....	.....	.....	.....	.....	.....
	16	10.55 a. m.	4.20 p. m.	2.14	10.59 a. m.	12.00 Noon	.01	.10	.23	.41	.58	.76	.96	1.09	1.25	1.42	1.51	1.67	1.81	.....	.....
	21	5.38 a. m.	7.18 a. m.	1.10	5.45 a. m.	6.21 a. m.	.01	.17	.34	.53	.68	.82	.96	1.04	.....	.....	.....	.....	.....	.....	.....
Modena, Utah	30	.....	.....	0.42	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.37	.....	.....	.....
Montgomery, Ala.	17	.....	.....	0.58	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.58	.....	.....	.....
Moorhead, Minn.	28	6.30 p. m.	7.40 p. m.	1.03	6.30 p. m.	7.16 p. m.	.00	.27	.43	.46	.48	.48	.55	.68	.81	.99	1.01	.....	.....	.....	.....
Mount Tamalpais, Cal.	.....	.....	.....	(‡)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mount Weather, Va.	25–26	.....	.....	1.21	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.60	.....	.....	.....
Nantucket, Mass.	15	11.20 a. m.	11.55 a. m.	0.79	11.32 a. m.	11.50 a. m.	.01	.15	.57	.75	.78	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
		12.25 p. m.	1.50 p. m.	1.18	12.27 p. m.	12.55 p. m.	.01	.31	.53	.66	.84	.99	1.06	.....	.....	.....	.....	.....	.....	.....	.....
Nashville, Tenn.	3	6.03 p. m.	9.35 p. m.	1.21	6.13 p. m.	7.00 p. m.	.01	.17	.33	.48	.61	.73	.83	.90	.96	1.01	1.06	.....	.....	.....	.....
	14	2.50 a. m.	4.00 a. m.	0.73	3.09 a. m.	3.24 a. m.	.05	.35	.54	.62	.64	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	26	2.03 p. m.	3.20 p. m.	0.63	2.07 p. m.	2.40 p. m.	.01	.15	.28	.35	.40	.43	.51	.55	.....	.....	.....	.....	.....	.....	.....
New Haven, Conn.	21	.....	.....	0.75	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.43	.....	.....	.....
New Orleans, La.	10	1.08 p. m.	2.15 p. m.	0.61	1.13 p. m.	1.38 p. m.	.01	.16	.17	.19	.39	.53	.....	.....	.....	.....	.....	.....	.....	.....	.....
	16	1.30 p. m.	1.55 p. m.	0.62	1.34 p. m.	1.46 p. m.	.01	.19	.58	.61	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	18	3.35 p. m.	6.15 p. m.	0.66	3.38 p. m.	4.03 p. m.	.02	.10	.25	.36	.46	.54	.....	.....	.....	.....	.....	.....	.....	.....	.....
	21	10.55 a. m.	12.10 p. m.	0.81	11.23 a. m.	11.46 a. m.	.02	.06	.22	.43	.59	.76	.....	.....	.....	.....	.....	.....	.....	.....	.....
	26	1.38 p. m.	2.20 p. m.	0.59	1.38 p. m.	1.55 p. m.	.00	.18	.40	.57	.51	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	31	2.20 p. m.	3.30 p. m.	1.40	2.26 p. m.	3.01 p. m.	.01	.31	.65	.98	1.16	1.24	1.31	1.37	.....	.....	.....	.....	.....	.....	.....
New York, N. Y.	21	3.29 p. m.	6.10 p. m.	1.11	3.36 p. m.	4.01 p. m.	T.	.20	.45	.72	.79	.92	.....	.....	.....	.....	.....	.....	.....	.....	.....
Norfolk, Va.	4	.....	.....	0.38	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.18	.....	.....	.....
Northfield, Vt.	29	.....	.....	1.04	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.24	.....	.....	.....
North Head, Wash.	6	.....	.....	0.10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.04	.....	.....	.....
North Platte, Nebr.	25	.....	.....	0.62	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.54	.....	.....	.....
Oklahoma, Okla.	29	.....	.....	0.82	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.45	.....	.....	.....
Omaha, Nebr.	31	.....	.....	0.95	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Oswego, N. Y.	29	.....	.....	0.44	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.39	.....	.....	.....
Palestine, Tex.	13	2.10 p. m.	3.05 p. m.	0.87	2.20 p. m.	2.32 p. m.	.03	.34	.70	.80	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	14	1.47 p. m.	3.25 p. m.	1.14	2.00 p. m.	2.26 p. m.	.06	.18	.42	.58	.76	.85	.87	.....	.....	.....	.....	.....	.....	.....	.....
	15	7.55 p. m.	10.25 p. m.	0.77	8.10 p. m.	8.25 p. m.	.02	.19	.43	.51	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Parkersburg, W. Va.	10	1.02 p. m.	1.50 p. m.	0.63	1.15 p. m.	1.46 p. m.	.03	.13	.29	.29	.36	.49	.58	.60	.....	.....	.....	.....	.....	.....	.....
Pensacola, Fla.	7	6.25 a. m.	10.50 a. m.	0.91	6.30 a. m.	6.47 a. m.	.01	.33	.51	.66	.71	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	10	8.05 a. m.	6.45 a. m.	0.75	5.11 a. m.	5.32 a. m.	.01	.09	.19	.39	.52	.57	.....	.....	.....	.....	.....	.....	.....	.....	.....
	21	1.20 a. m.	4.15 a. m.	0.88	1.28 a. m.	2.03 a. m.	.02	.07	.27	.52	.69	.74	.77	.....	.....	.....	.....	.....	.....	.....	.....
	30	12.35 p. m.	2.30 p. m.	1.81	1.12 p. m.	1.44 p. m.	.05	.38	.72	1.10	1.41	1.58	1.70	1.75	.....	.....	.....	.....	.....	.....	.....
Peoria, Ill.	10	10.42 a. m.	12.25 p. m.	1.00	11.22 a. m.	12.10 p. m.	.04	.06	.21	.40	.42	.44	.45	.57	.80	.89	.93	.....	.....	.....	.....
Philadelphia, Pa.	21	3.25 p. m.	4.15 p. m.	1.18	3.30 p. m.	3.52 p. m.	.01	.21	.59	.98	1.10	1.14	.....	.....	.....	.....	.....	.....	.....	.....	.....
Phoenix, Ariz.	29	.....	.....	0.29	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.20	.....	.....	.....
Pierre, S. Dak.	4	4.55 p. m.	5.40 p. m.	0.94	5.06 p. m.	5.33 p. m.	.01	.13	.28	.37	.55	.82	.92	.....	.....	.....	.....	.....	.....	.....	.....
Pittsburgh, Pa.	11	8.55 a. m.	5.45 p. m.	1.82	10.12 a. m.	11.12 a. m.	.29	.06	.22	.29	.39	.41	.42	.42	.46	.53	.58	.82	.....	.....	.....
Pocatello, Idaho.	1	.....	.....	0.03	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.03	.....	.....	.....
Point Reyes Light, Cal.	.....	.....	.....	(‡)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Port Huron, Mich.	10	2.09 p. m.	4.10 p. m.	0.95	2.12 p. m.	2.38 p. m.	.01	.21	.46	.69	.78	.88	.91	.....	.....	.....	.....	.....	.....	.....	.....
Portland, Me.	11	.....	.....	0.43	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.37	.....	.....	.....
Portland, Oreg.	3	.....	.....	0.01	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.01	.....	.....	.....
Providence, R. I.	21	2.49 p. m.	7.44 p. m.	1.17	2.49 p. m.	3.22 p. m.	.00	.10	.24	.44	.51	.63	.73	.77	.....	.....	.....	.....	.....	.....	.....
Pueblo, Colo.	2	3.39 p. m.	4.40 p. m.	0.65	3.47 p. m.	4.07 p. m.	.02	.17	.40	.49	.56	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	20	2.25 p. m.	4.10 p. m.	0.82	3.32 p. m.	3.49 p. m.	.09	.11	.25	.45	.52	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during August, 1914, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.												
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Raleigh, N. C.	14			0.95														.45			
Rapid City, S. Dak.	19			0.58														.54			
Reading, Pa.	29	7.36 p. m.	8.48 p. m.	0.81	7.44 p. m.	8.04 p. m.	.02	.16	.60	.67	.78										
Red Bluff, Cal.				(‡)																	
Reno, Nev.	2			0.38														.35			
Richmond, Va.	10			0.52														.52			
Rochester, N. Y.	10	1.34 p. m.	2.18 p. m.	0.59	1.41 p. m.	1.58 p. m.	.01	.16	.39	.52	.56										
	18	4.55 a. m.	6.55 a. m.	1.24	5.33 a. m.	6.49 a. m.	.16	.14	.38	.48	.55	.59	.61	.62	.70	.73	.83	.87	1.07		
	24	1.55 a. m.	6.15 a. m.	1.17	2.39 a. m.	3.04 a. m.	.18	.09	.21	.43	.56	.65									
Roseburg, Oreg.	3			T.														T.			
Roswell, N. Mex.	30			0.49														.28			
Sacramento, Cal.				(‡)																	
Saginaw, Mich.	10	4.18 p. m.	6.40 p. m.	1.79	4.20 p. m.	5.28 p. m.	.01	.08	.20	.37	.45	.47	.58	.64	.76	.83	1.18	1.47	1.74		
	18	D. N. a. m.	8.07 a. m.	2.91	4.03 a. m.	4.45 a. m.	.80	.14	.29	.43	.58	.67	.78	.89	1.04	1.09					
	18–19	9.15 p. m.	D. N. a. m.	0.80	10.03 p. m.	10.30 p. m.	.03	.31	.42	.47	.54	.62	.66								
St. Joseph, Mo.	31	1.10 a. m.	3.30 a. m.	0.68	3.02 a. m.	3.22 a. m.	.01	.35	.55	.66											
St. Louis, Mo.	19	1.50 p. m.	2.38 p. m.	1.00	1.50 p. m.	2.16 p. m.	.00	.20	.43	.61	.82	.92									
	31	3.05 a. m.	4.50 a. m.	0.64	3.24 a. m.	3.39 a. m.	.06	.26	.48	.57											
St. Paul, Minn.	9	3.53 p. m.	8.35 p. m.	1.46	5.51 p. m.	6.52 p. m.	.14	.22	.35	.46	.69	.75	.77	.78	.78	.81	.89	1.15	1.21		
	22	7.35 p. m.	10.45 p. m.	1.30	7.52 p. m.	8.20 p. m.	.11	.13	.14	.26	.63	.82	.90								
Salt Lake City, Utah	3			0.22														.21			
San Antonio, Tex.	5	2.24 p. m.	4.45 p. m.	0.69	2.40 p. m.	3.09 p. m.	.01	.11	.28	.42	.68	.56									
	6	3.15 a. m.	6.38 a. m.	2.38	4.06 a. m.	5.08 a. m.	.11	.09	.22	.48	.92	1.05	1.15	1.28	1.49	1.61	1.99	2.13			
San Diego, Cal.				‡																	
Sand Key, Fla.	11			0.26														.26			
Sandusky, Ohio.	17			1.04														.72			
San Francisco, Cal.				‡																	
San Jose, Cal.				‡																	
San Luis Obispo, Cal.	7			T.														T.			
Santa Fe, N. Mex.	10	2.47 p. m.	3.26 p. m.	0.95	2.51 p. m.	3.26 p. m.	.01	.21	.42	.55	.62	.73	.87	.94							
Sault Ste. Marie, Mich.	13			0.56														.46			
Savannah, Ga.	16	7.40 p. m.	10.55 p. m.	0.74	8.01 p. m.	8.19 p. m.	.04	.16	.25	.47	.59										
	21	6.50 p. m.	9.02 p. m.	0.76	6.54 p. m.	7.17 p. m.	.01	.17	.34	.50	.59	.63									
Scranton, Pa.	10			0.48														.46			
Seattle, Wash.	16			0.01														.01			
Sheridan, Wyo.	1			0.25														.14			
Shreveport, La.	11	1.10 p. m.	1.45 p. m.	0.55	1.22 p. m.	1.36 p. m.	.03	.25	.40	.51											
Sioux City, Iowa.	4			0.47														.35			
Spokane, Wash.	6			0.01														.01			
Springfield, Ill.	13			0.47														.42			
Springfield, Mo.	24–25			2.00														(*)			
Syracuse, N. Y.	20			0.91														.77			
Tacoma, Wash.	6			T.														T.			
Tampa, Fla.	11	5.05 p. m.	6.15 p. m.	0.64	5.23 p. m.	5.47 p. m.	.05	.18	.32	.42	.49	.54									
	13	3.28 p. m.	4.35 p. m.	0.59	3.28 p. m.	3.39 p. m.	.00	.31	.52	.54											
	19	4.46 p. m.	7.15 p. m.	0.88	5.08 p. m.	5.33 p. m.	.01	.15	.34	.52	.68	.75									
Tatoosh Island, Wash.	6			0.47														.17			
Taylor, Tex.	7	D. N. a. m.	4.05 p. m.	2.27	12.35 p. m.	1.34 p. m.	1.13	.09	.16	.24	.32	.41	.49	.57	.64	.75	.89	1.04			
	14–15	6.06 p. m.	D. N. a. m.	1.94	6.39 p. m.	7.07 p. m.	.15	.12	.28	.55	.84	.99	1.04								
Terre Haute, Ind.	9	12.25 p. m.	1.20 p. m.	0.72	12.33 p. m.	1.07 p. m.	.01	.15	.28	.40	.48	.50	.56	.68							
	25	D. N. a. m.	10.40 a. m.	1.28	5.10 a. m.	5.45 a. m.	.37	.11	.33	.46	.55	.61	.66	.71							
Thomasville, Ga.	10	12.44 p. m.	4.35 p. m.	0.76	12.57 p. m.	1.13 p. m.	.03	.28	.54	.62	.64										
	24	1.27 p. m.	2.20 p. m.	0.63	1.35 p. m.	1.55 p. m.	.01	.25	.38	.49	.55										
Toledo, Ohio.	10	3.22 p. m.	3.53 p. m.	0.60	3.32 p. m.	3.47 p. m.	.01	.19	.46	.57											
		4.35 p. m.	8.40 p. m.	1.25	5.22 p. m.	6.04 p. m.	.04	.33	.56	.65	.72	.80	.84	.90	.99	1.03					
Tonopah, Nev.	6,14			0.01														.01			
Topeka, Kans.	27			1.20														.54			
Valentine, Nebr.	1	6.03 a. m.	7.45 a. m.	0.72	6.54 a. m.	7.23 a. m.	.05	.05	.11	.31	.46	.54	.61								
	20	6.14 a. m.	8.50 a. m.	0.99	6.41 a. m.	6.56 a. m.	.05	.22	.48	.62											
Vicksburg, Miss.	9	5.01 p. m.	5.55 p. m.	0.82	5.04 p. m.	5.28 p. m.	.01	.24	.48	.59	.67	.72									
	29	3.40 a. m.	4.55 a. m.	0.70	3.46 a. m.	4.12 a. m.	.01	.28	.40	.48	.50	.64	.67								
Walla Walla, Wash.	6			T.														T.			
Washington, D. C.	11	5.43 p. m.	7.00 p. m.	1.01	5.52 p. m.	6.20 p. m.	.01	.13	.24	.47	.60	.86	.92								
	28–29	7.19 p. m.	12.39 a. m.	2.71	8.45 p. m.	9.11 p. m.	.06	.08	.17	.44	.75	.95	.98								
					9.37 p. m.	10.24 p. m.	1.09	.12	.17	.18	.23	.33	.48	.65	1.03	1.28	1.31				
Wichita, Kans.	19	12.24 p. m.	12.52 p. m.	0.75	12.27 p. m.	12.47 p. m.	.01	.16	.35	.63	.74										
	27	4.21 p. m.	7.45 p. m.	1.25	5.00 p. m.	5.37 p. m.	.06	.08	.17	.31	.45	.60	.81	1.07	1.13						
Williston, N. Dak.	24			2.04														.46			
Wilmington, N. C.	7	2.02 p. m.	2.45 p. m.	1.00	2.06 p. m.	2.20 p. m.	.01	.32	.78	.98											
	13	1.55 p. m.	6.10 p. m.	1.80	2.15 p. m.	3.27 p. m.	.03	.21	.33	.44	.59	.73	.92	1.05	1.13	1.25	1.38	1.49	1.64		
Winnemucca, Nev.	27,28			T.														T.			
Wytheville, Va.	21	12.27 p. m.	12.50 p. m.	0.58	12.29 p. m.	12.45 p. m.	.01	.25	.40	.52	.57										
Yankton, S. Dak.	4			0.58														.53			
Yellowstone Park, Wyo.	28			0.04														.04			

* Self-register not working. † Record partly estimated. ‡ No precipitation occurred during month.

TABLE III.—*Data furnished by the Canadian Meteorological Service, August, 1914.*

Stations.	Pressure.			Temperature.						Precipitation.		
	Station reduced to mean of 24 hours.	Sea-level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+ mean min.÷2.	Departure from normal.	Mean maximum.	Mean minimum.	Highest.	Lowest.	Total.	Departure from normal.	Total. snowfall.
	Inches.	*Inches.*	*Inches.*	*°F*	*°F*	*°F*	*°F*	*°F*	*°F*	*Inches.*	*Inches.*	
St. Johns, N. F.	29.77	29.90	−.06	60.4	+0.6	67.4	53.4	82	48	3.71	−0.37	.....
Sydney, C. B. I.	29.95	29.99	+.04	63.6	+0.3	73.0	54.1	84	40	2.40	−1.22	.....
Halifax, N. S.	29.91	30.01	+.05	63.5	−0.1	73.2	53.7	84	42	5.12	+ .77	.....
Yarmouth, N. S.	29.95	30.02	+.05	60.0	−0.2	66.2	53.9	73	44	3.79	− .22	.....
Charlottetown, P. E. I.	29.94	29.98	+.04	64.5	+0.2	73.0	56.0	85	47	2.01	−1.63	.....
Chatham, N. B.	29.95	29.97	+.04	64.2	+1.0	75.1	53.4	90	43	3.03	−1.01	.....
Father Point, Que.	29.91	29.93	+.02	56.6	+1.0	65.2	48.0	88	42	1.22	−1.83	.....
Quebec, Que.	29.65	29.97	+.04	63.1	0.0	72.6	53.6	90	41	3.93	+ .10	.....
Montreal, Que.	29.78	29.98	+.03	66.1	−0.3	74.6	57.6	91	48	4.81	+1.24	.....
Stonecliffe, Ont.	29.39	29.99	+.03	62.2	−1.0	74.6	49.7	94	36	2.45	− .50	.....
Ottawa, Ont.	29.73	30.05	+.09	68.7	+3.9	73.7	53.7	85	42	2.52	− .51	.....
Kingston, Ont.	29.69	29.99	+.01	69.2	+2.2	75.2	63.2	91	54	2.17	− .21	.....
Toronto, Ont.	29.58	29.94	−.05	68.1	+2.1	77.7	58.4	92	48	5.19	+2.43	.....
White River, Ont.	29.65	29.95	−.01	56.0	−0.4	71.5	40.0	86	22	1.77	−1.53	.....
Port Stanley, Ont.	29.35	29.98	−.02	67.1	+1.2	76.2	58.0	84	46	6.92	+4.50	.....
Southampton, Ont.	29.31	.....	.....	65.0	+1.2	73.3	56.6	87	41	3.32	+1.07	.....
Parry Sound, Ont.	29.31	29.99	+.01	65.2	+1.7	76.3	54.2	99	40	2.76	+ .04	.....
Port Arthur, Ont.	29.26	29.97	+.01	59.6	+0.1	68.6	50.7	79	34	4.48	+ .73	.....
Winnipeg, Man.	29.12	29.94	.00	62.7	−0.7	74.3	51.2	95	38	2.05	− .62	.....
Minnedosa, Man.	28.16	29.95	+.01	61.8	+2.4	76.4	47.3	98	32	0.82	−1.28	.....
Qu'Appelle, Sask.	27.69	29.90	−.03	59.8	−1.7	73.4	46.3	88	32	1.81	+ .17	.....
Medicine Hat, Alberta	27.66	29.87	−.05	68.8	+3.1	84.6	53.0	102	37	0.66	−1.01	.....
Swift Current, Sask.	27.37	29.87	−.06	63.4	−0.6	79.8	47.0	100	32	0.51	−1.40	.....
Calgary, Alberta	26.44	29.90	−.01	61.8	+2.4	76.6	47.0	96	36	2.18	+ .04	.....
Banff, Alberta	25.44	29.96	+.05	57.0	+0.7	73.4	40.5	89	28	0.59	−1.94	.....
Edmonton, Alberta	27.65	29.90	−.02	60.4	+1.6	72.9	48.0	85	41	2.52	+ .39	.....
Prince Albert, Sask.	28.34	29.88	−.04	57.4	−1.5	67.5	47.4	82	35	0.80	−1.35	.....
Battleford, Sask.	28.20	29.94	+.03	63.0	+0.4	76.2	49.9	90	35	2.30	− .06	.....
Kamloops, B. C.	28.74	29.93	+.02	68.7	+0.1	83.9	53.6	95	43	0.38	− .71	.....
Victoria, B. C.	29.81	30.06	+.05	59.4	+0.7	67.3	51.6	82	46	0.18	− .42	.....
Barkerville, B. C.	25.75	30.04	+.14	51.9	−4.4	65.3	38.5	72	28	0.96	−2.14	.....
Hamilton, Bermuda	30.05	30.21	+.11	78.8	−0.8	84.7	73.0	87	69	4.78	−1.30	.....

Chart I. Hydrographs of Several Principal Rivers, August, 1914.

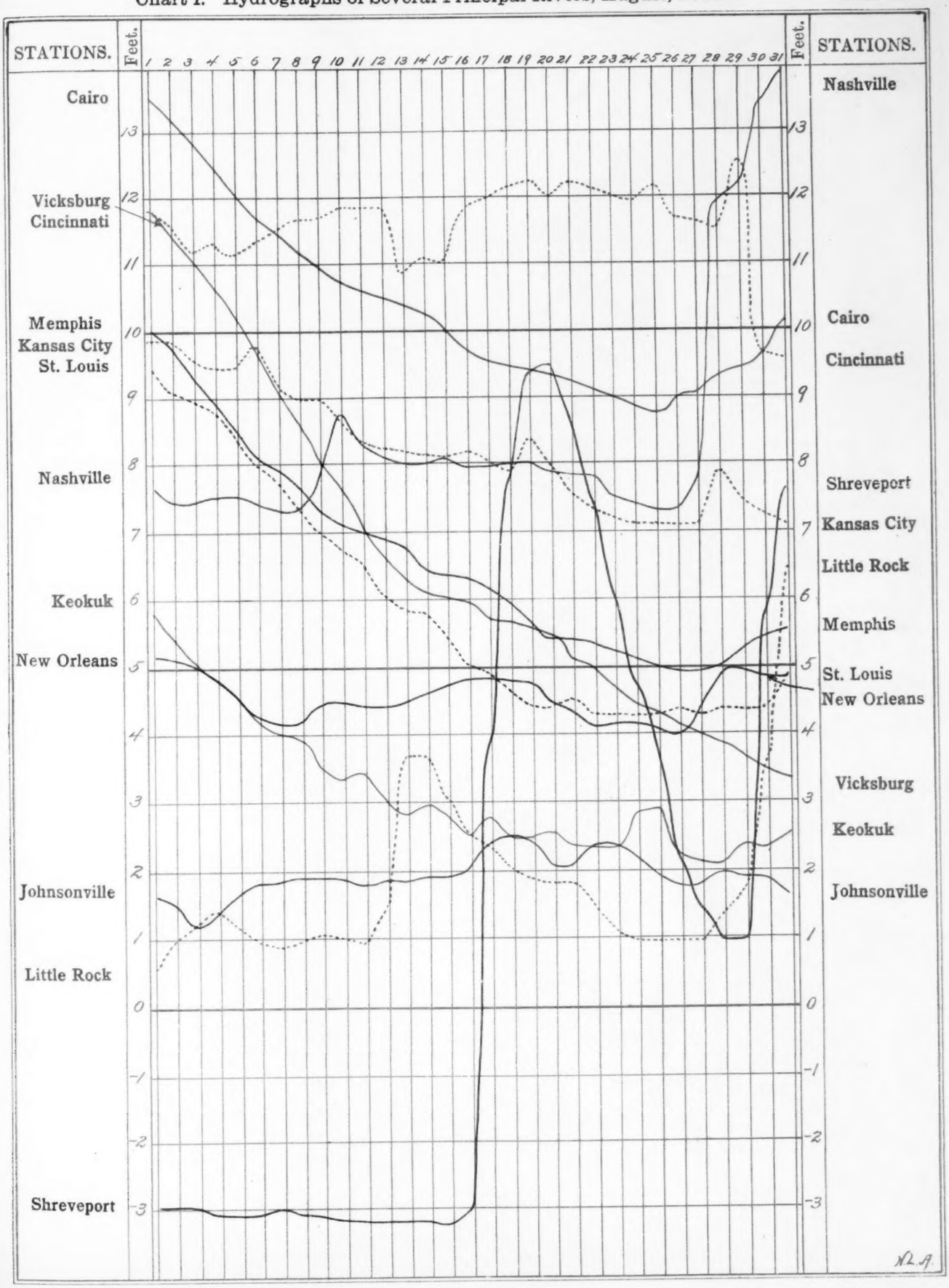

Chart II. Tracks of Centers of High Areas, August, 1914.

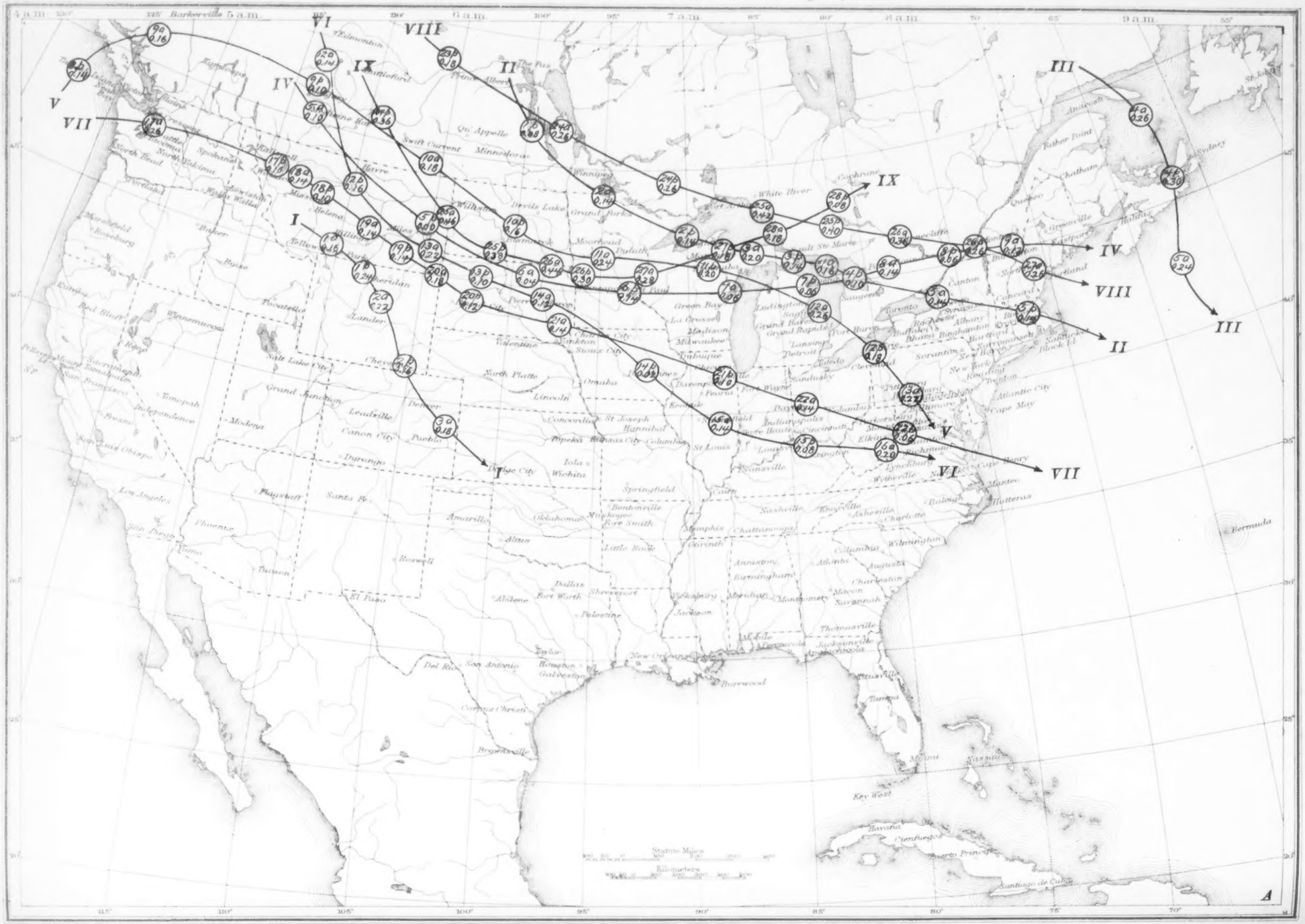

Chart III. Tracks of Centers of Low Areas, August, 1914.

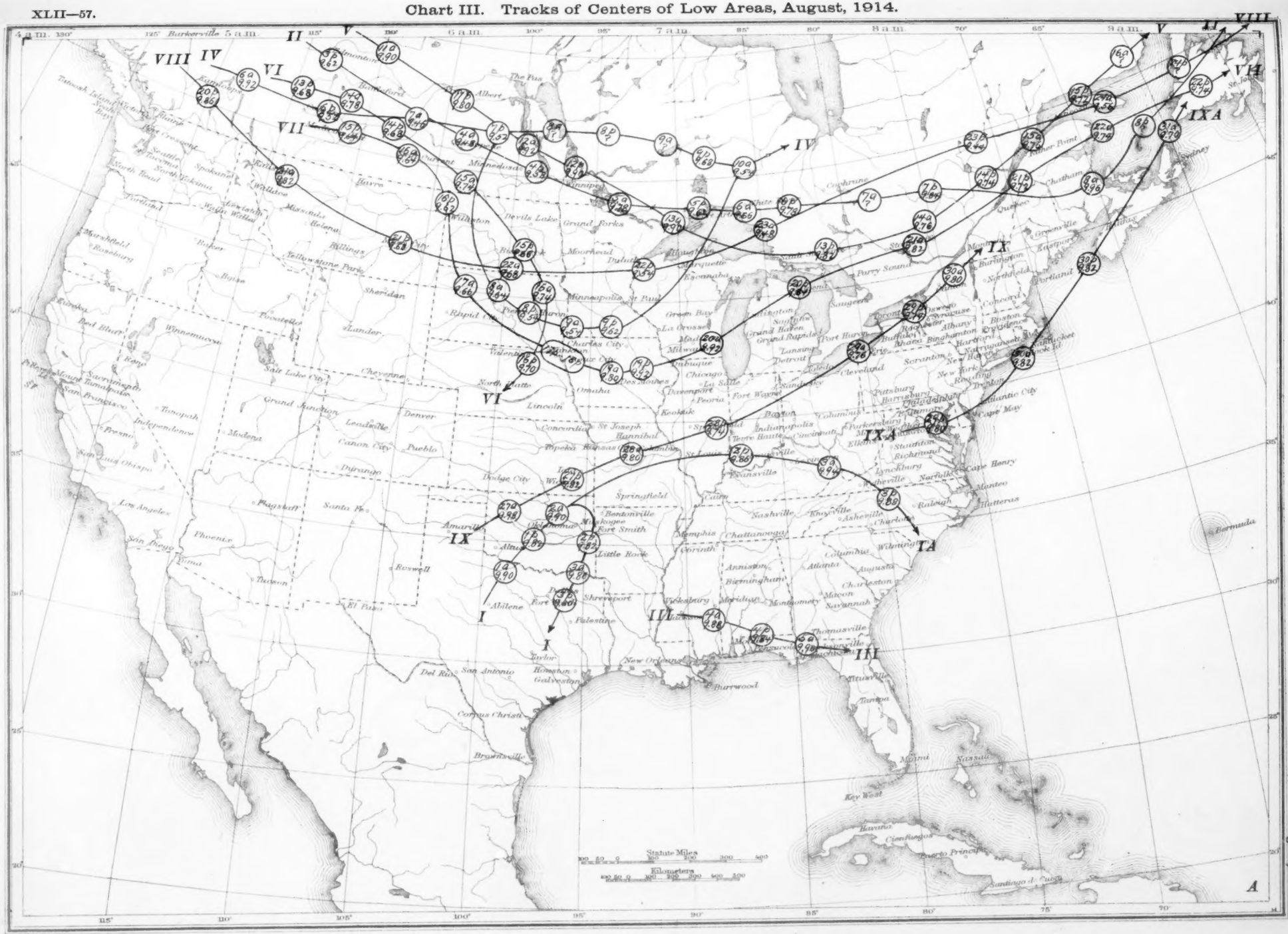

Chart IV. Departure of the Mean Temperature from the Normal, August, 1914.

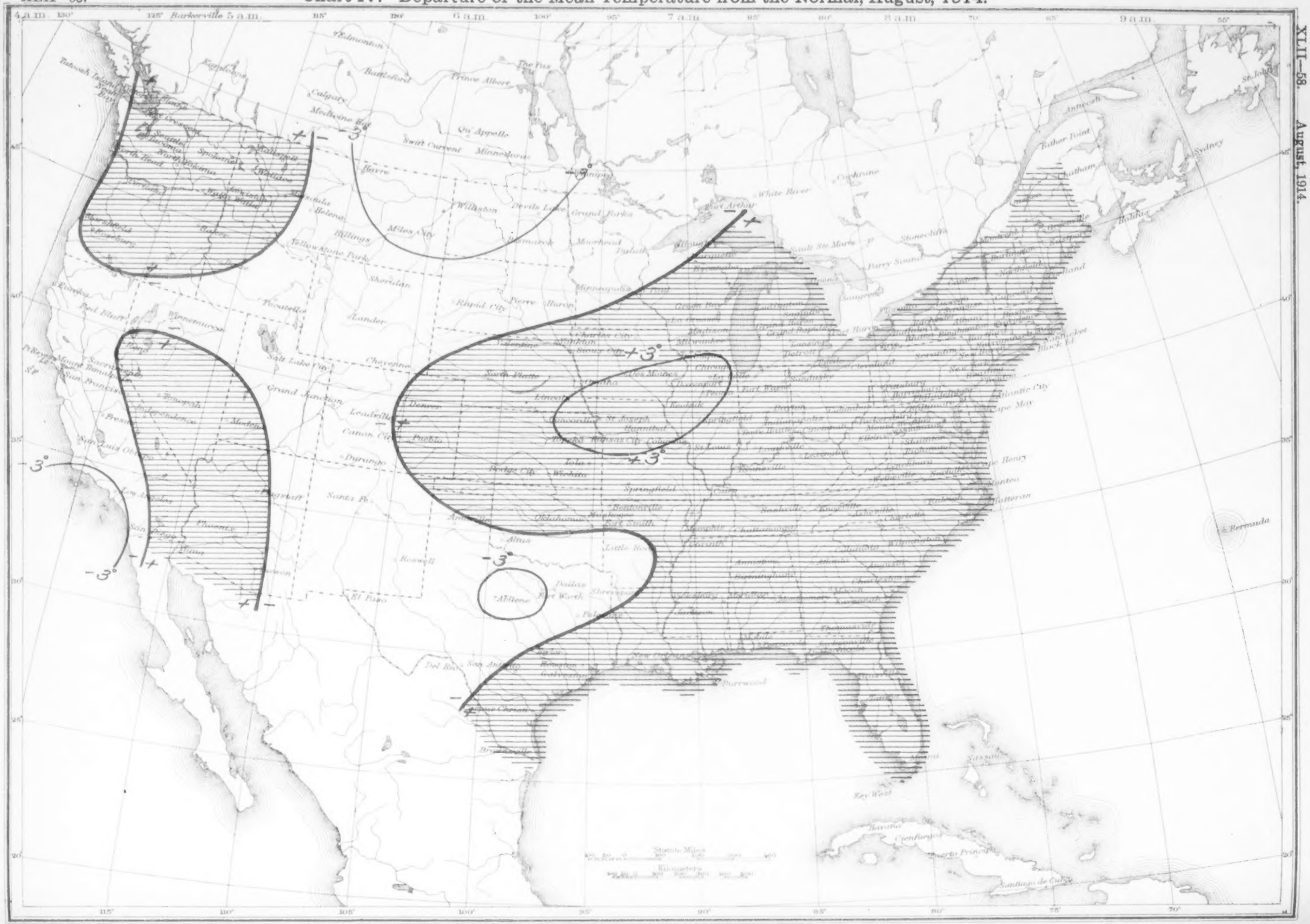

Chart V. Total Precipitation, inches, August, 1914.

Chart V. Total Precipitation, inches, August, 1914.

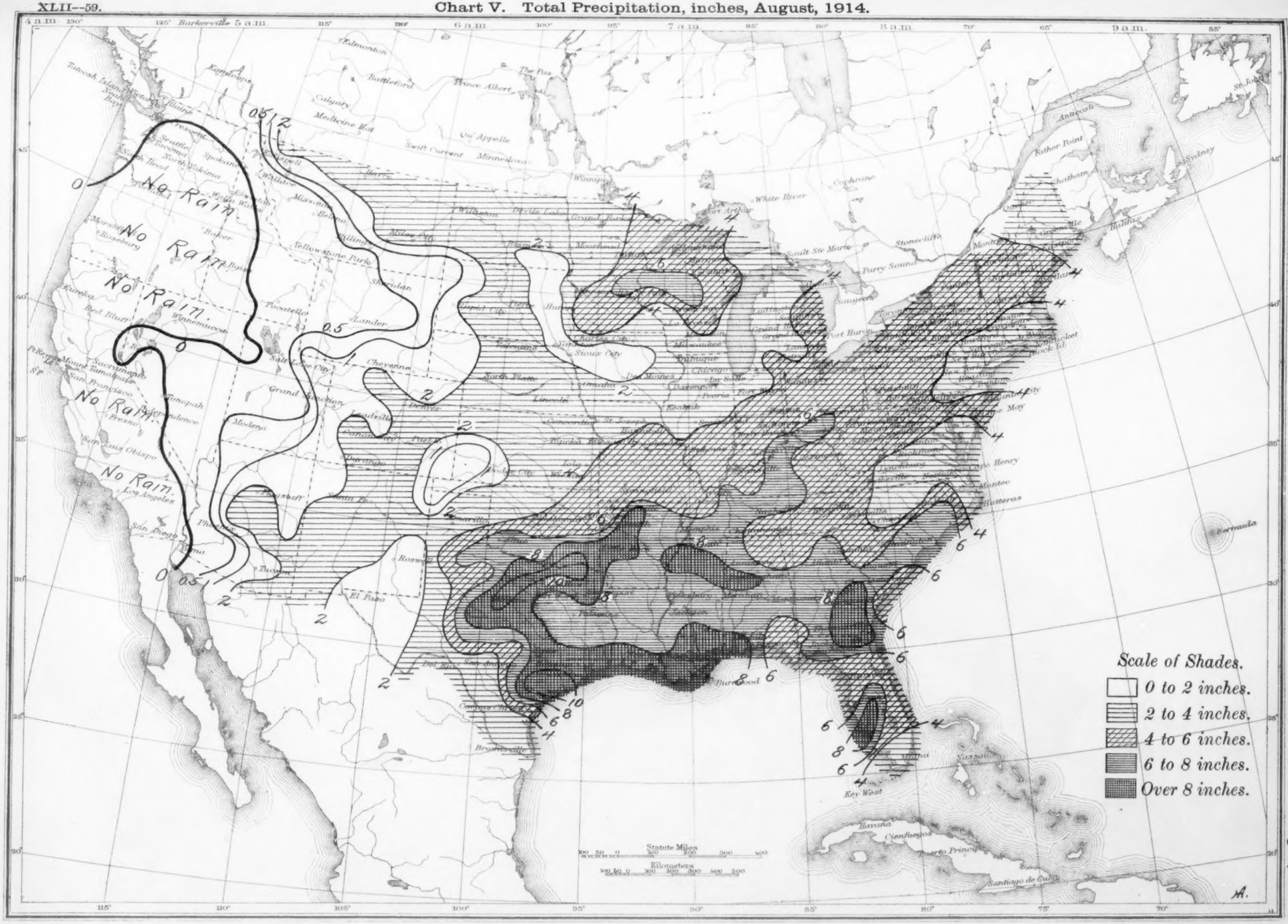

Chart VI. Percentage of Clear Sky between Sunrise and Sunset, August, 1914.

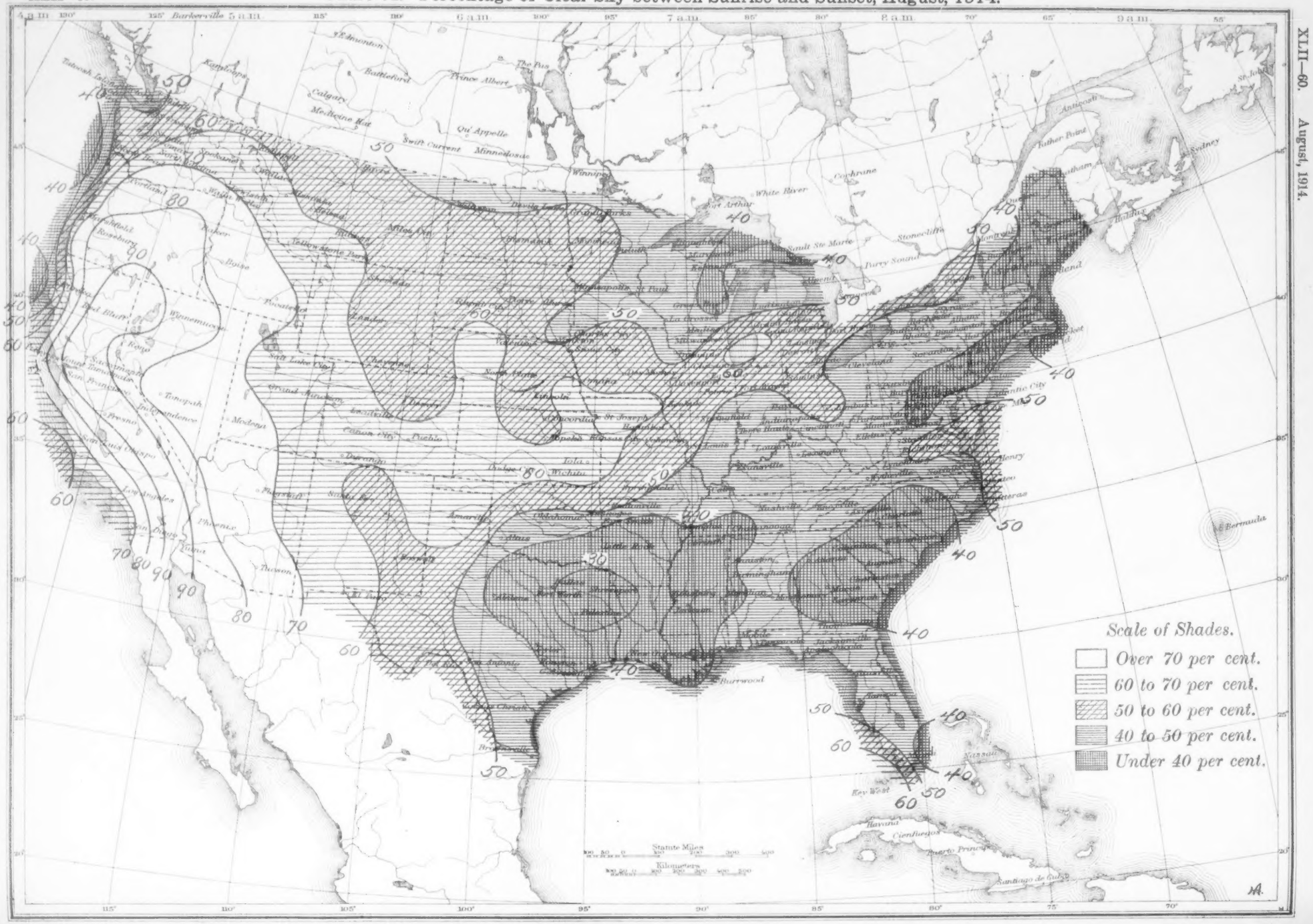
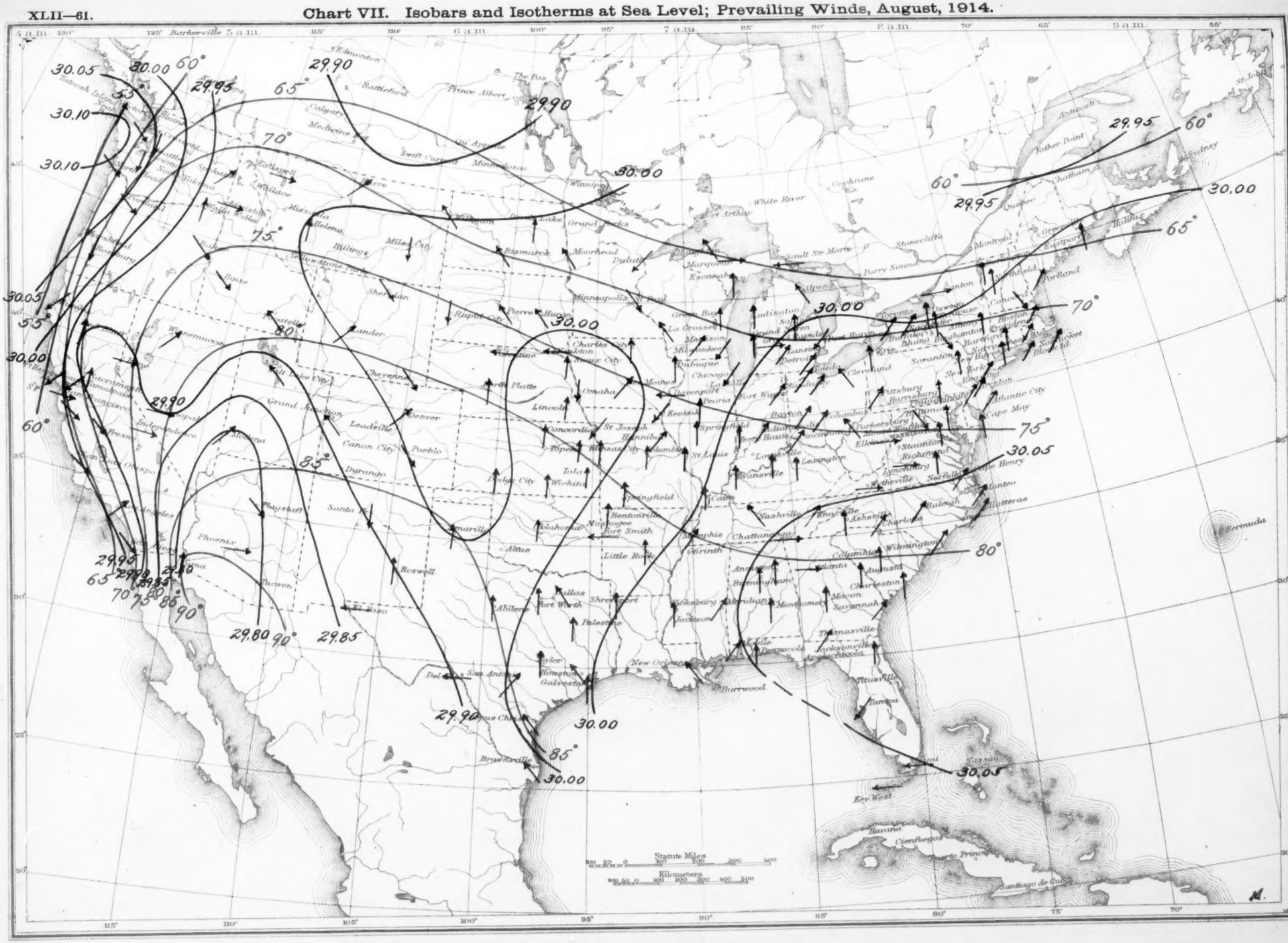
Chart VII. Isobars and Isotherms at Sea Level; Prevailing Winds, August, 1914.